B_s Mixing and CP Violation at Tevatron

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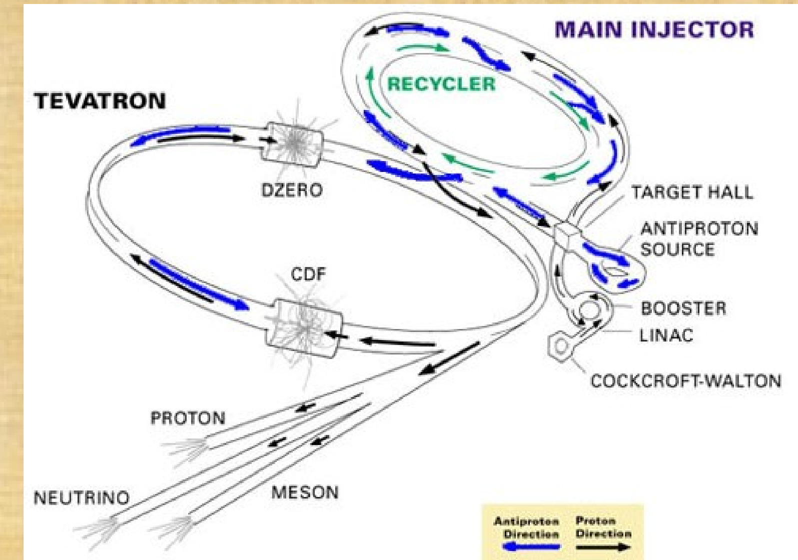
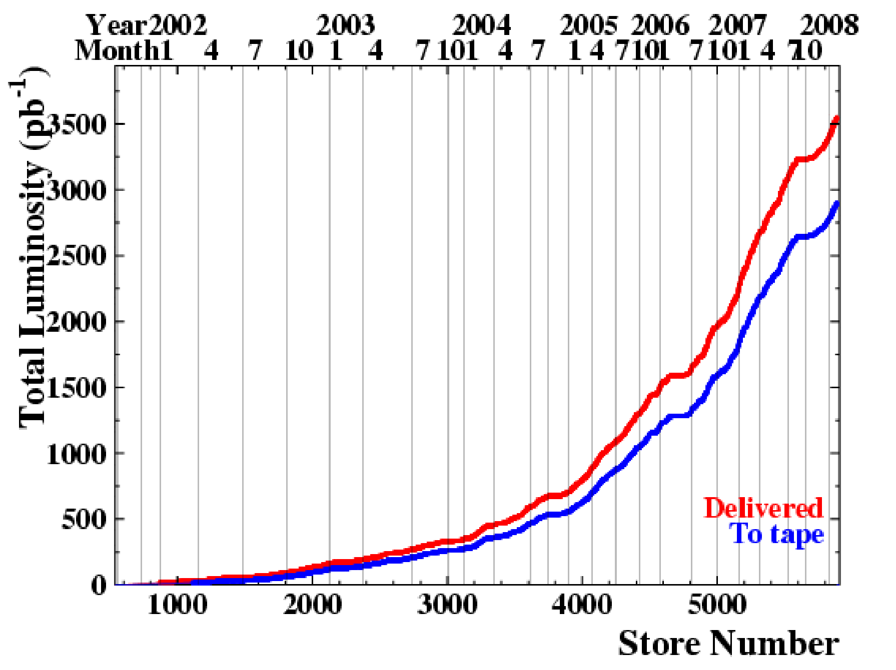
Workshop on the Origin oc P, CP, T Violation
ICTP July 5th 2008

Topics
- B_s mixing
  - First measurement of sin2β_s at TeVatron
  - Other B_s mixing phase related measurement
  - Outlook
- More B_s physics
  - Direct CP violation
  - Semileptonic asymmetry

The Tevatron

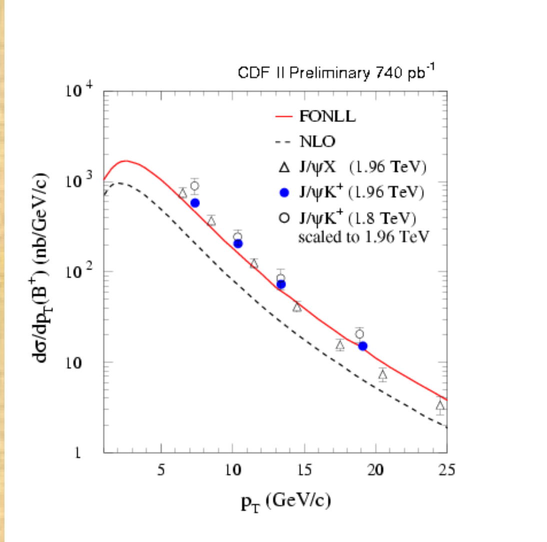
- $p\bar{p}$ collisions at 1.96 TeV
- Excellent Performance
- Peak Initial Luminosity recent record: 3.15 x 10^{32} cm^{-2} s^{-1}
- Challenge for Detectors, Triggers and Reconstructions



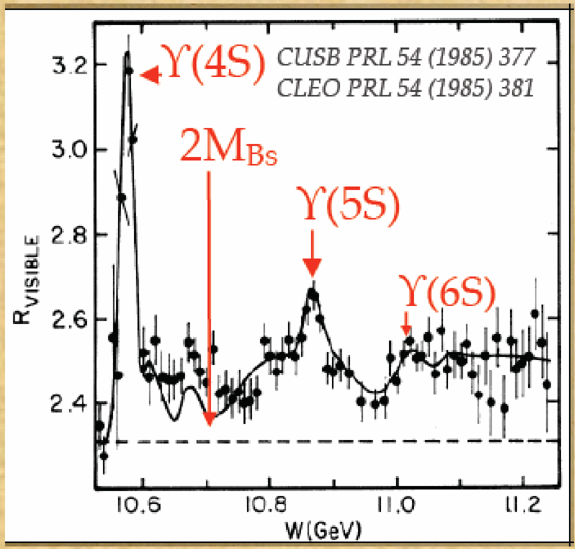


- The analyses presented in this talk span from 1.35 to 2.8 fb^{-1}
- Currently on tape > 3.5 fb^{-1}
- Plan to accumulate up 6 fb^{-1} in 2009, 8 fb^{-1} possible if 2010 extension approved
- x4 – x5 current dataset

Tevatron vs Υ(4S) vs Υ(5S)

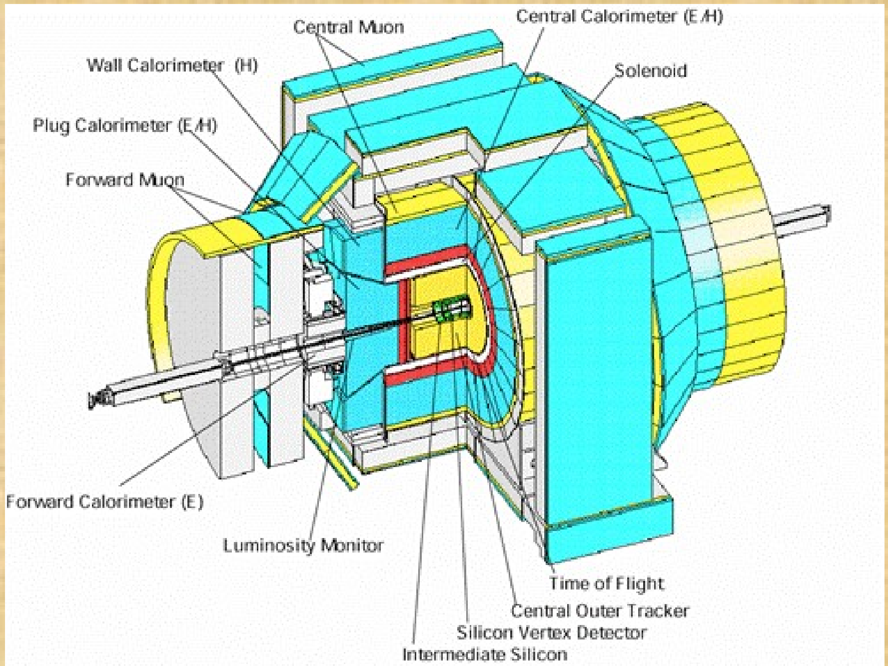


- Cross section of O (μb) in typical detector acceptance
- Pair produce (uncorrelated) all sort of b-hadrons ($B_{u,d}$, B_s, B_c, Λ_b…)
- Significant Lorentz Boost: $<\beta\gamma>=P_b/M_b\sim 2$
- Hadronic enivronment : $\sigma(pp)_{tot}=60$ mb
- Multi purpose detector



- Cross section of O (nb)
- Pair produce (correlated) only $B_{u,d}$, B_s only at Υ(5S)
- Small and fixed Lorentz Boost: $\beta\gamma=0.425$ (Belle/KEK-B)
- Extra clean enivronment and dedicated detectors

Tevatron Detectors

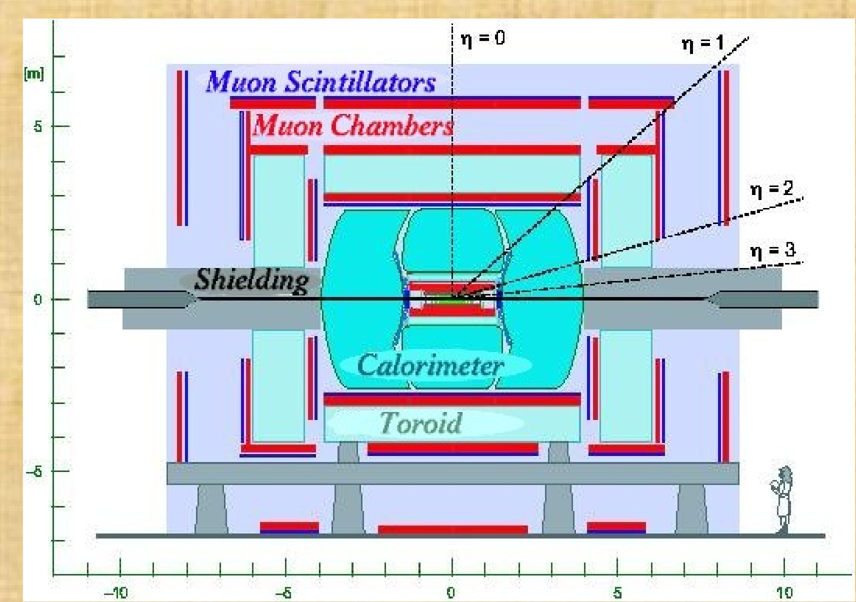


CDF II Detector

- Tracker: - Silicon Vertex Detector
  - Drift Chambers
- **Excellent Momentum Resolution**
- **Particle ID**: TOF and dE/dx
- Muon Coverage (Trigger) $|\eta|<1$
- Displaced vertex trigger (SVT)

DØ Detector

- **New L00** installed in 2006!
- Solenoid: 2T, weekly reversed polarity
- Excellent Calorimetry and electron ID
- **Muon Coverage (Trigger)** $|\eta|< 2.2$

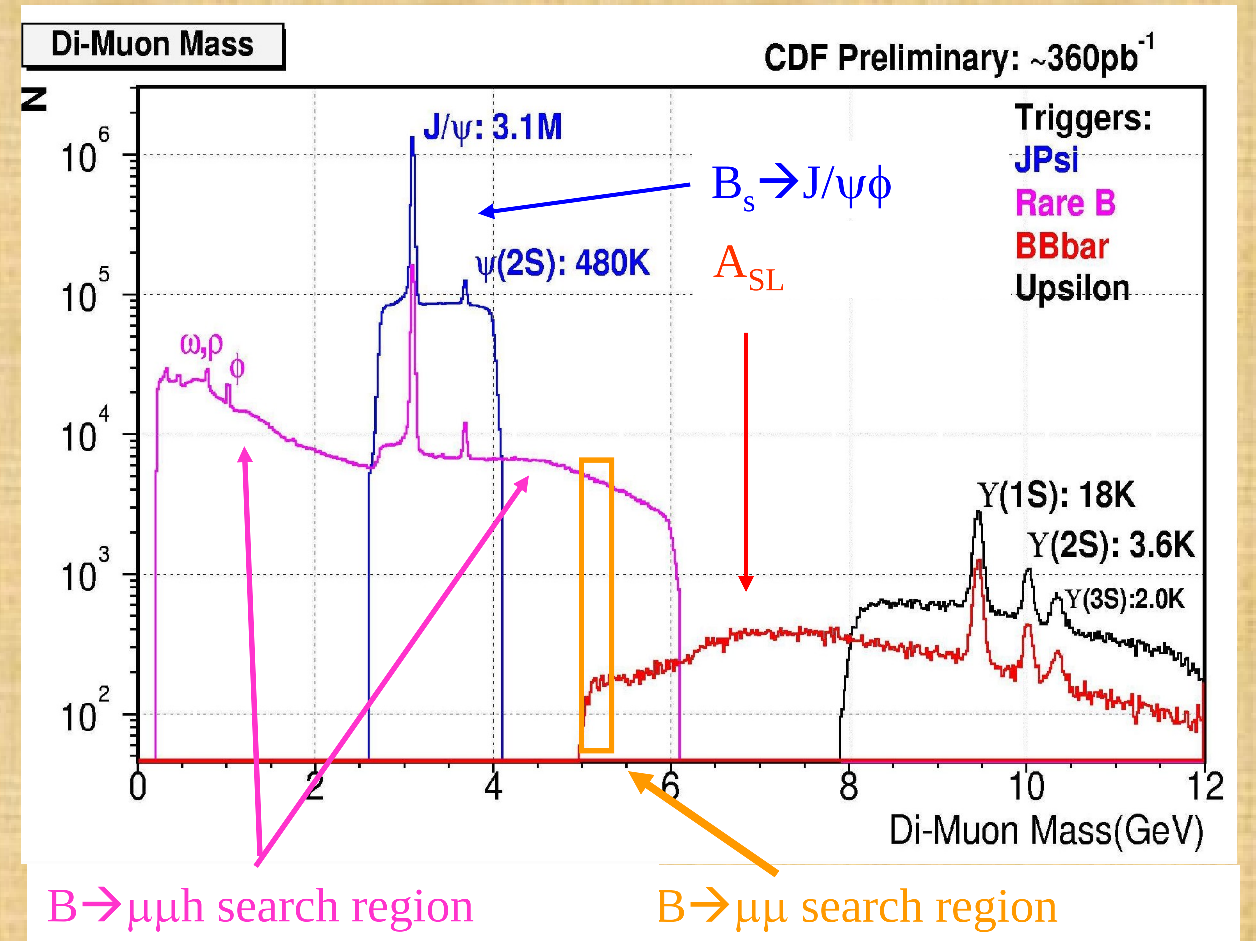


Triggering at collider

- Cannot over-enphasize
- Physics analysis at colliders start from triggering the data!
- B-physics program at CDF/Tevatron practically run off the:
  - Displaced track trigger
    - Track reconstruction at Level1
    - Silicon Vertex Tracker at Level2
    - Kinematic selection → select hadronic B-decays
  - Di-muon trigger
    - Two identified muon identified at L1/L2/L3
    - Select inculusive bbbar events and events with J/psi

Dimuon Triggers

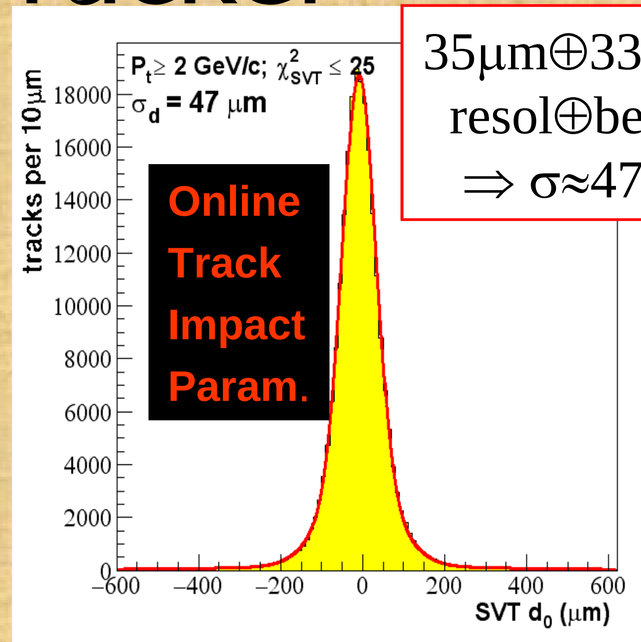
- **CDF:**
  - di-muon triggered data
  - Two rapidity ranges: CMU $|\eta|<0.6$, CMX $0.6 < |\eta| < 1$
  - $p_T(\mu)>1.5$ or 2.0 GeV/c



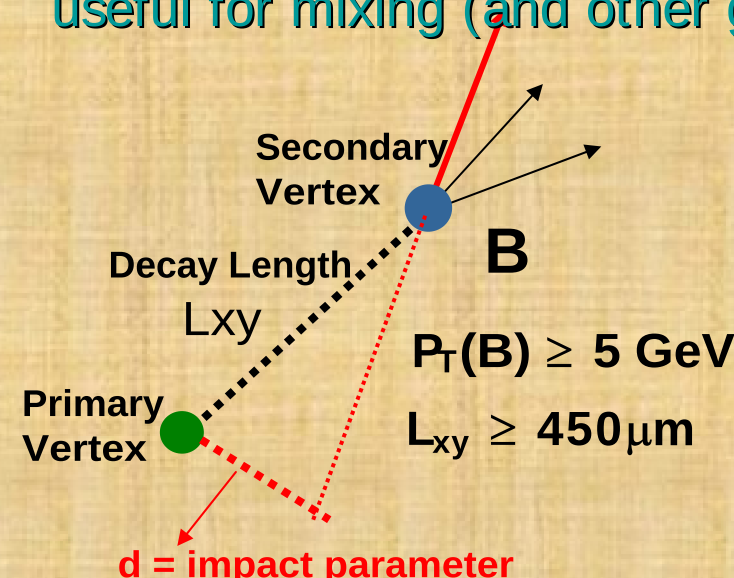
- **DØ:**
  - Similar thresholds
  - Greater rapidity acceptance

Silicon Vertex Tracker

- Triggering on displaced vertex at CDF using SVT, main novelty in Run II, the hall-mark of CDF Run II physics program:
  - Discovery of B_s mixing
  - Charmless decays
  - Σ_B discovery
- The necessary tool to get fully reconstructed decays hadronic b decays useful for mixing (and other good stuff…)



35μm⊕33μm
resol⊕beam
⇒ σ≈47μm



$P_T(B) \geq 5$ GeV

$L_{xy} \geq 450\mu m$

Main Trigger requires:

- 2 opposite charge tracks,
- $P_t \geq 2$ GeV/c,
- impact parameter $|d_0| > 120\ \mu m$
- Scalar pt sum > 5.5 GeV/c
- Projected decay length $L_{xy} > 200\ \mu m$
- $2° < \Delta\phi < 90°$

Add a dynamically prescaled LOWPT trigger with no opposite charge and no Pt sum to fill available bandwidth at low luminosity

Different Types of CP violation

- All three types of CP violation can be tested at Tevatron:
  - Direct CP violation in beauty (and charm!) decays
  - CP violation through interference of mixing and decays in $B_s \rightarrow J/\psi\ \phi$
  - CP violation in mixing (semileptonic asymmetry)

- Highlight result for the B_s sector in the following (but $B_{d,u}$ result are as good or better than at B-factories for several channels)

Direct CP violation in $B_{d,s} \rightarrow K\pi$

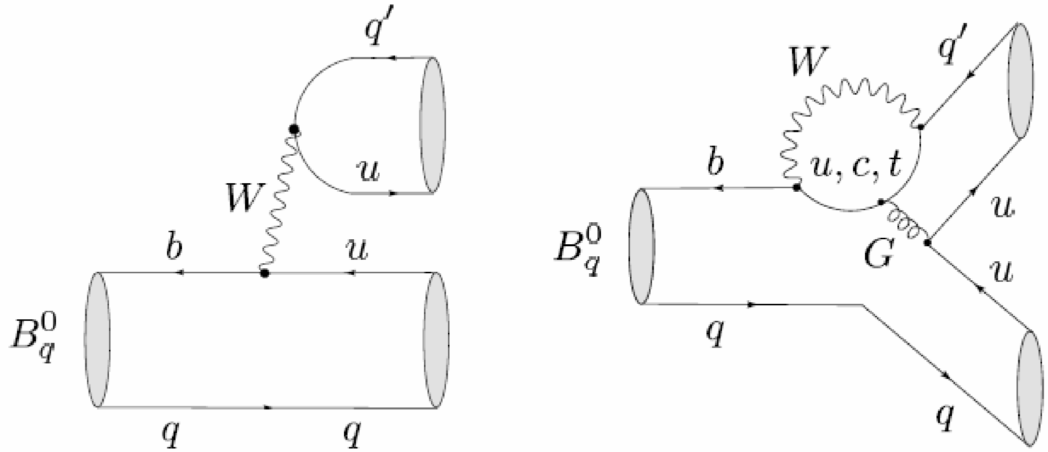
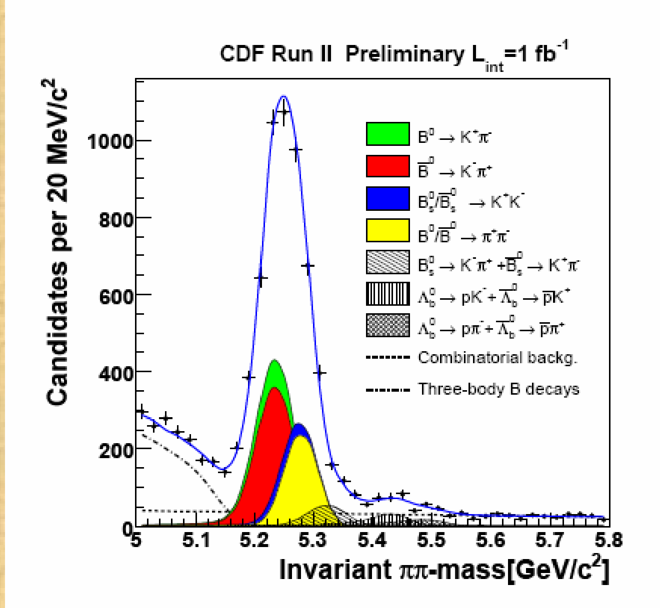


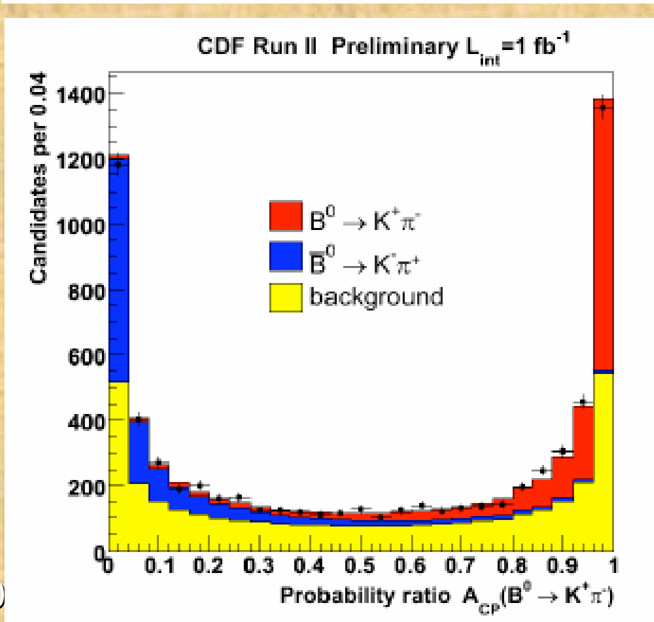
Figure 1: Tree and penguin topologies contributing to the U-spin-related $B_d^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$ and $B_d^0 \to \pi^- K^+$, $B_s^0 \to \pi^+ K^-$ decays ($q, q' \in \{d, s\}$).

- Tree – Penguin amplitudes may generate sizeable direct CP violation
- Sensitive to CKM angle γ
- Theory predictions uncertain (strong phases)
- Useful combining B_d and B_s to test/use flavour symmetries (U-spin, SU(3) etc.)

$B_{d,s} \rightarrow hh'$ Signal

- Large signal selected through the displaced track trigger
- Superposition of $B_d \rightarrow K\pi$, $B_d \rightarrow \pi\pi$, $B_s \rightarrow KK$, $B_s \rightarrow K\pi$ + $\Lambda_b(p\pi/K)$
- Need multidimensional unbinned likelihood fit to kinematics + dE/dx information to disentangle various component
- Signal yield and resolution comparable to B-factories (with 1 fb^{-1} of Tevatron data)
- High precision measurement:
  - CPV in $B_d \rightarrow K\pi$ A_{CP}=-0.086±0.023±0.006 (4050 ev.)
- Compare to:
  - Babar A_{CP}=-0.107±0.018 +0.007 -0.004 (4400 ev.)
  - Belle A_{CP}=-0.086±0.018±0.008 (4100 ev.)
- Systematics/detector asymmetries kept under control using also huge samples of kinematically similar $D^0 \rightarrow hh'$ decays





Direct CP violation in $B_{s(d)}$ decays

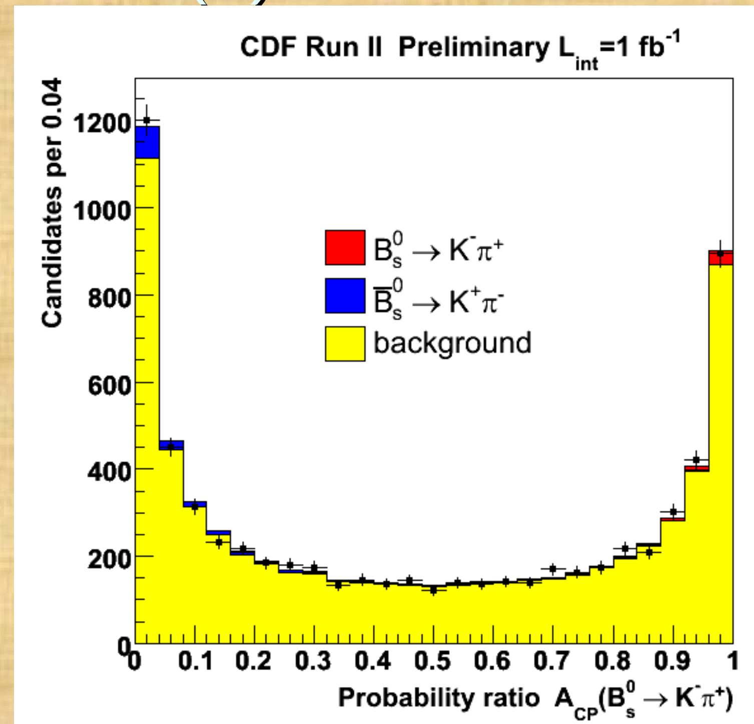
- With $1fb^{-1}$ first observation of $B_s \rightarrow K\pi$ mode:

$$N(B_s^0 \rightarrow K^{-}\mathrm{p}^{+}) = 230 \pm 34\ (stat) \pm 16\ (syst)\ [8\mathrm{s}\ \ signif\,]$$

- First measurement of direct CP violation:

$$A_{CP} = \frac{N(\overline{B}_s^0 \rightarrow \mathrm{K}^{+}\mathrm{p}^{-}) - N(B_s^0 \rightarrow K^{-}\mathrm{p}^{+})}{N(\overline{B}_s^0 \rightarrow \mathrm{K}^{+}\mathrm{p}^{-}) + N(B_s^0 \rightarrow K^{-}\mathrm{p}^{+})}$$

$$A_{CP}(B_s^0 \rightarrow K^{-}\mathrm{p}^{+}) = 0.39 \pm 0.15\ (stat) \pm 0.08\ (syst)$$



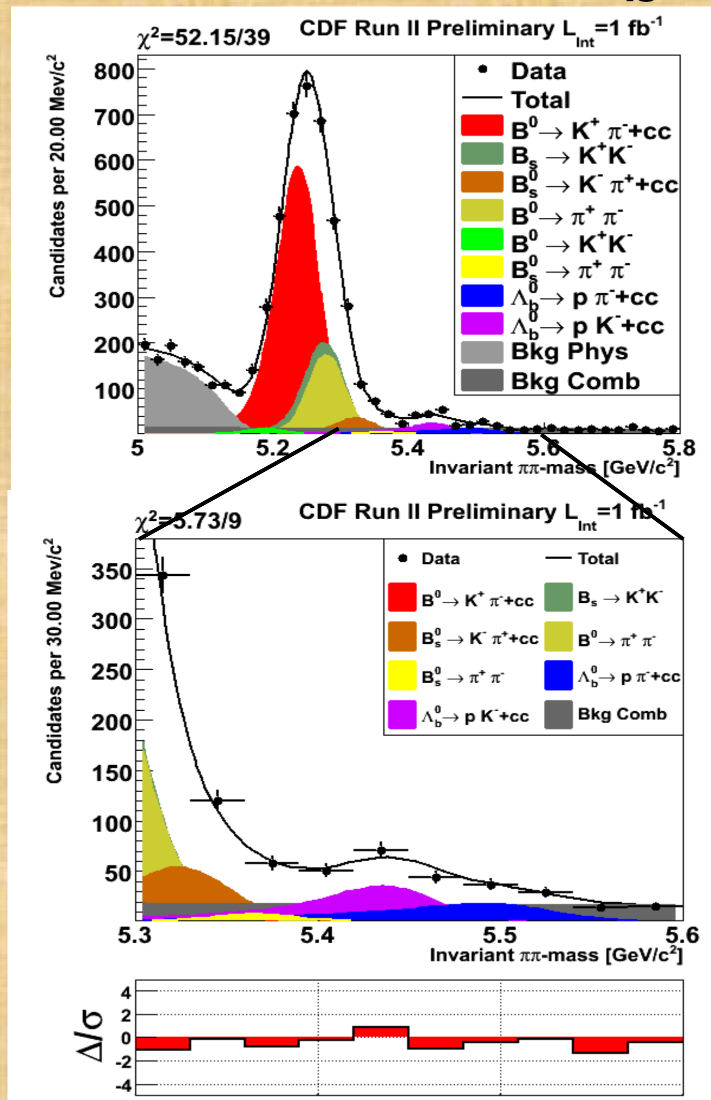
- A_{CP} is 2.5σ different from 0
- Compatible with expectation [H.J.Lipkin, Phys. Lett. B **621**, 126 (2005)]

$$|A(B_s \to \pi^+ K^-)|^2 - |A(\bar{B}_s \to \pi^- K^+)|^2 = |A(\bar{B}_d \to \pi^+ K^-)|^2 - |A(B_d \to \pi^- K^+)|^2$$

$$\Downarrow$$

$$A_{CP}(\overline{B}_s^0 \rightarrow \mathrm{K}^{+}\mathrm{p}^{-}) = -A_{CP}(\overline{B}_d^0 \rightarrow \mathrm{K}^{-}\mathrm{p}^{+}) \cdot \frac{BR(\overline{B}_d^0 \rightarrow \mathrm{K}^{-}\mathrm{p}^{+})}{BR(\overline{B}_s^0 \rightarrow \mathrm{K}^{+}\mathrm{p}^{-})} \cdot \frac{\tau_{B_s}}{\tau_{B_d}} \approx 0.37$$

$\Lambda_b \to ph$ results



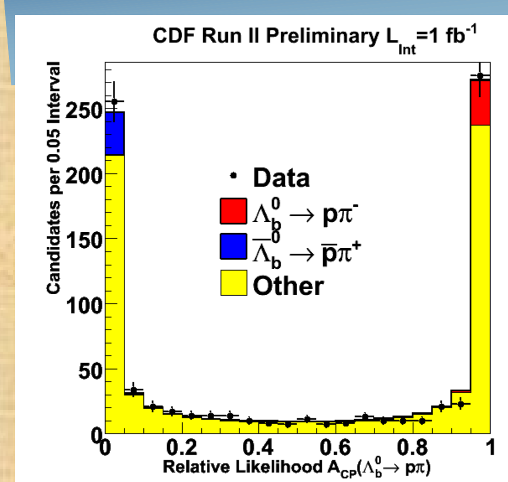
- Observation of charmless Λ_b decays:

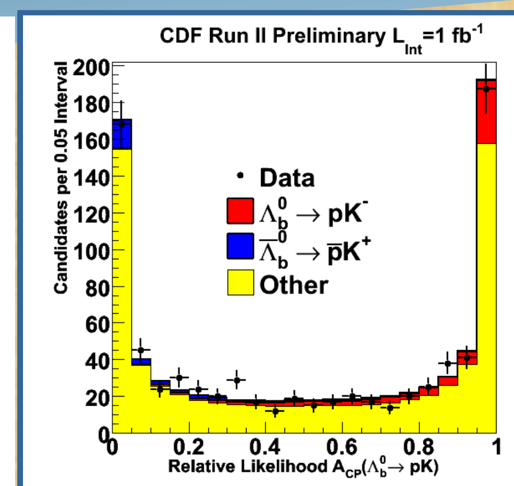
$BR(\Lambda_b^0 \to pK) = (5.0 \pm 0.7 \pm 1.0) \times 10^{-6}$
$BR(\Lambda_b^0 \to p\pi) = (3.1 \pm 0.6 \pm 0.7) \times 10^{-6}$
(Assuming PDG value $f_{baryon}/f_d = 0.25 \pm 0.04$)
Predicted:
$BR(\Lambda_b^0 \to pK) = 2 \times 10^{-6}$
$BR(\Lambda_b^0 \to p\pi) = 1 \times 10^{-6}$

- First hints of DCPV in barion decays (2σ)?

$$A_{CP}(\Lambda_b \to pp) = 0.03 \pm 0.17\ (stat) \ldots$$

$$A_{CP}(\Lambda_b \to pK) = 0.37 \pm 0.17\ (stat) \pm 0.03\ (syst)$$

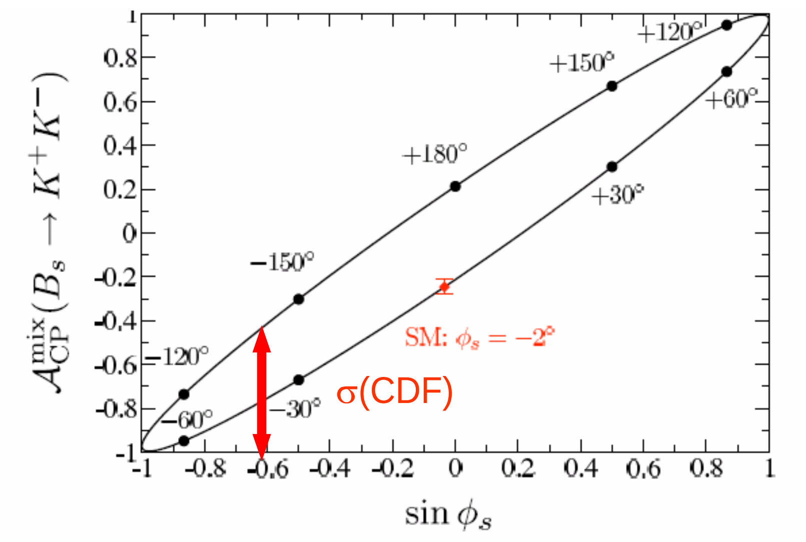


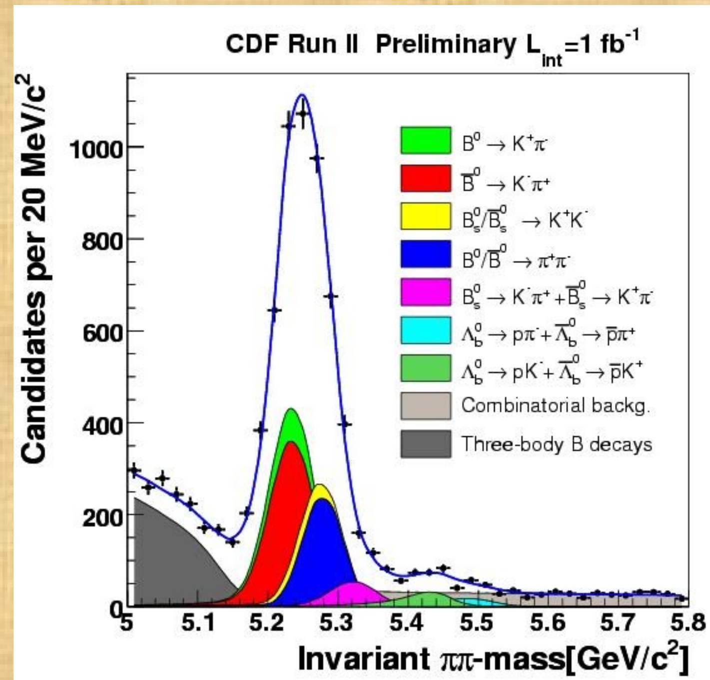


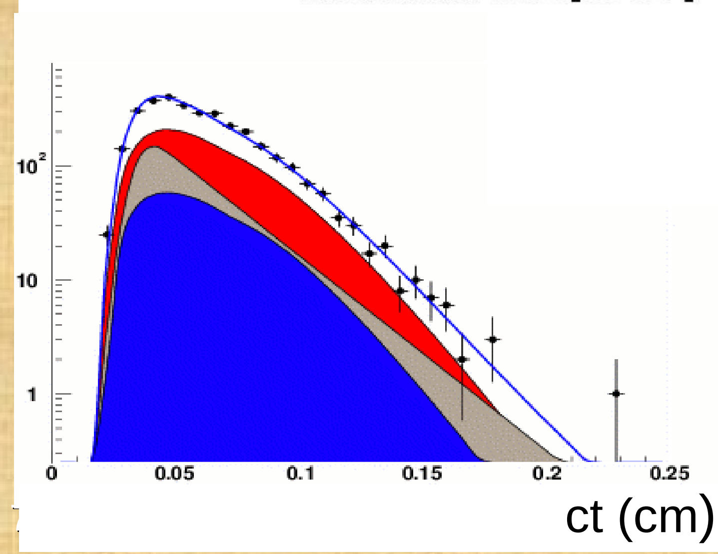
Lifetime and A_{CP} $B_s \rightarrow K^+K^-$

- CDF has 1300 $B_s \rightarrow K^+K^-$ events in $1fb^{-1}$
- Expect 25 μm in $B_s \rightarrow K^+K^-$ lifetime determination (measure τ_L in SM)
- May reach O(30%) ACP_{mix} at the end of Run II

Fleischer:0705.1121 [hep-ph]

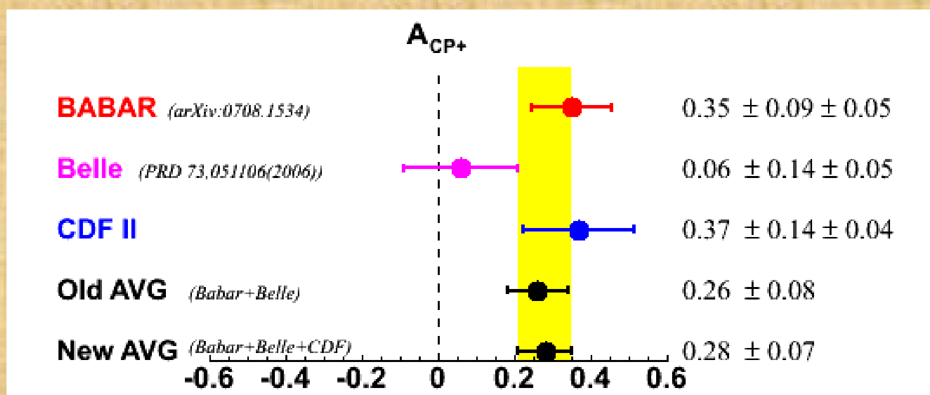


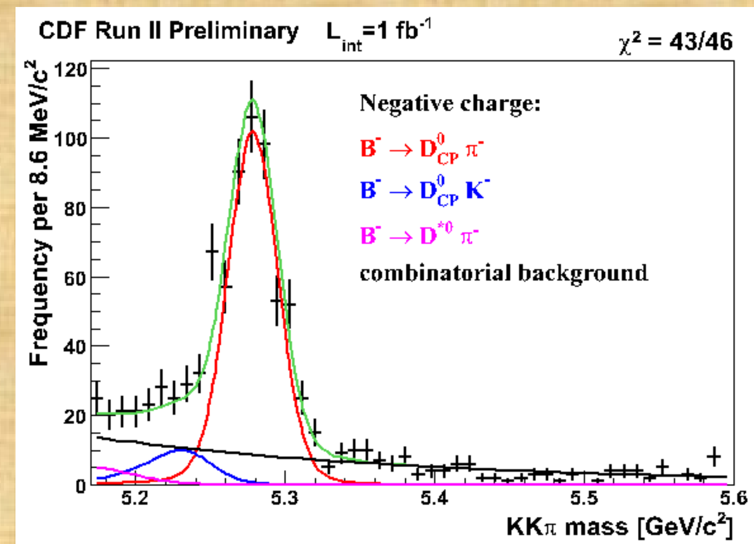


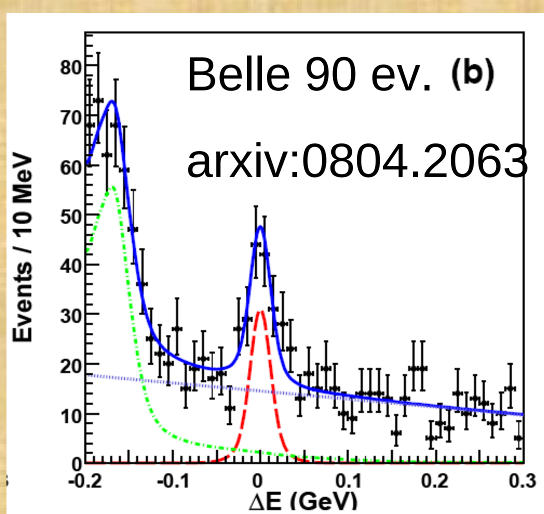


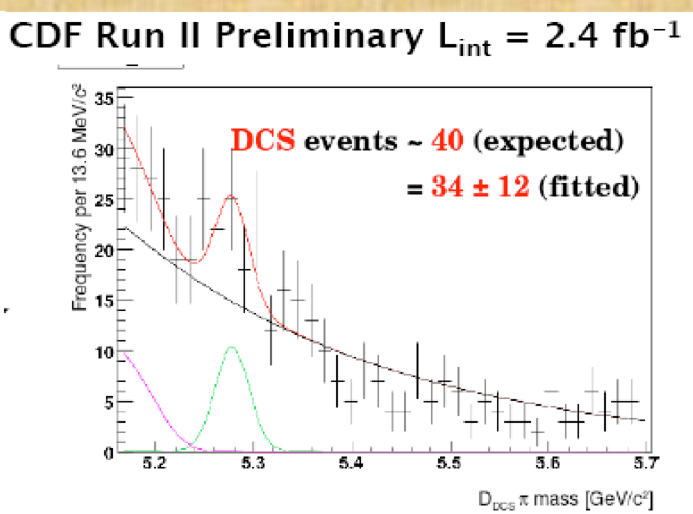
DCPV $B^{\pm} \rightarrow DK^{\pm}$ at CDF

- Significant number of $B^{\pm} \rightarrow DK^{\pm}$ events (this analysis ~120 $B \rightarrow D_{CP}K$ events)
- Cabibbo suppressed D^0 decays (CP+) firmly established: kinematics + PID separation, resolution as Babar/Belle









CDF contributing to "γ" via GLW method, now looking also for double Cabibbo suppressed D^0 modes for ADS method

Flavor mixing

- Flavor eigenstate ≠ Hamiltonian eigenstate
  - transition between meson and anti-meson exists
- Simplified Schroedinger equation describing mixing and decay

$$i\frac{d}{dt}\begin{pmatrix} B_q^0(t) \\ \overline{B_q^0}(t) \end{pmatrix} = (M - \frac{i}{2}\Gamma)\begin{pmatrix} B_q^0 \\ \overline{B_q^0} \end{pmatrix} \qquad \begin{pmatrix} M_{11} & M_{12} \\ M_{12}^* & M_{22} \end{pmatrix};\begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{22} \end{pmatrix}$$

- The mass and lifetime eigenstates (with $\Gamma_{12}/M_{12} << 1$)

$$|B_L> = p|B_q^0> + q|\overline{B}_q^0> \qquad \Delta m_q = m_H - m_L = 2|M_{12}^q|$$

$$|B_H> = p|B_q^0> - q|\overline{B}_q^0> \qquad \Delta\Gamma_q = \Gamma_L - \Gamma_H \cong -2|\Gamma_{12}^q|\mathrm{Re}(\frac{\Gamma_{12}^q}{M_{12}^q}) = 2|\Gamma_{12}^q|\cos(\varphi_s)$$

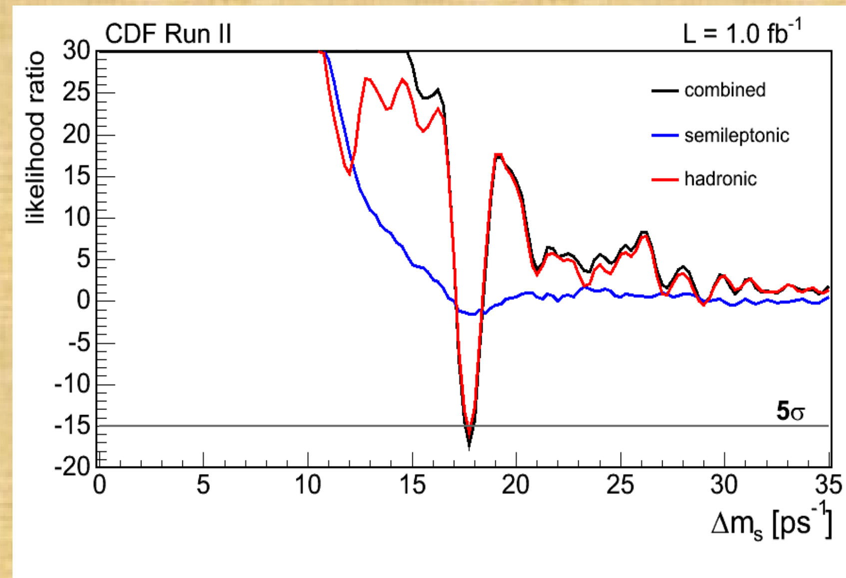
M_{12} and Γ_{12} are the focus of CDF & DØ experiments in the B_s system

$|M_{12}|$ and Δm_s

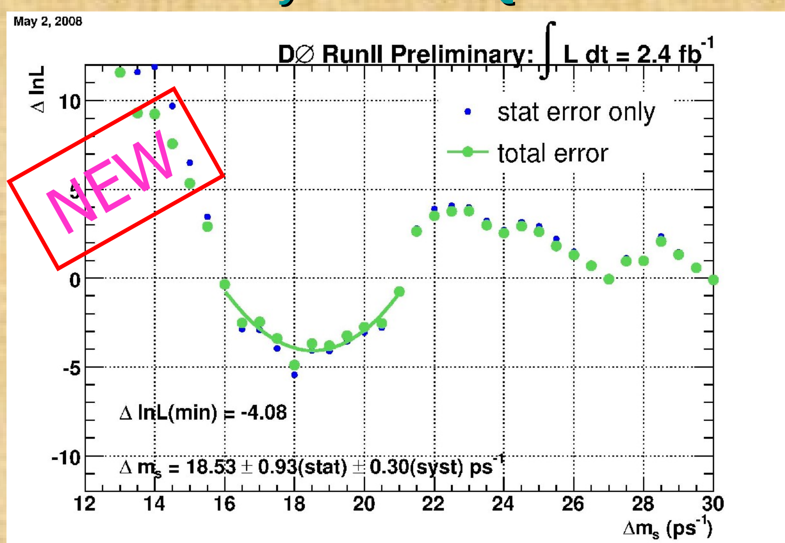
- Oscillation observed at CDF in 2006 with $1 fb^{-1}$ of data
- Δm_s known with great precision:

$$\Delta m_s = 17.77 \pm 0.10(stat) \pm 0.07\, ps^{-1}$$

$$\frac{|V_{td}|}{|V_{ts}|} = 0.2060 \pm 0.0007(\exp)^{+0.0081}_{-0.0060}(theor)$$



- Comparision with SM prediction limited by lattice QCD uncertainty!



- 3σ significance (stat. only) obtained at DØ ($2.4 fb^{-1}$)
- DØ note 5618:

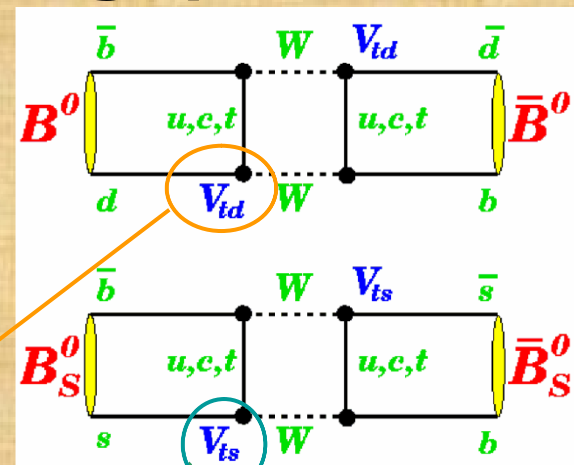
$$\Delta m_s = 18.53 \pm 0.90(stat) \pm 0.30(syst)\;\; ps^{-1}$$

- Consistent with CDF result

What about Mixing phase?

- In the SM phase of the mixing amplitude connected to the phase of CKM elements:

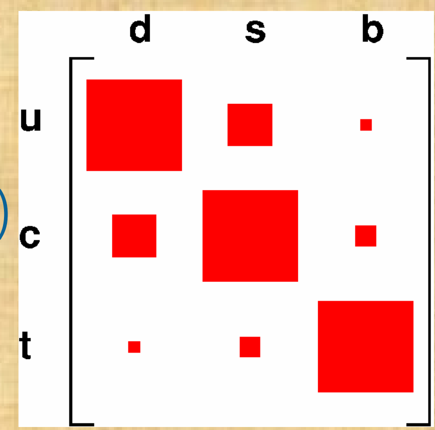
$$\Phi_M = \arg(V_{tb}V_{ts}^*)^2$$



- In the Wolfenstain Parametrization (expanding in terms of $\lambda=\sin(\theta_c)\sim 0.23$ to $O(\lambda^5)$)
  - η responsible for CP Violation $\Rightarrow \eta \neq 0$ implies CPV

$$V_{CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ \boxed{A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho-i\eta)]} & \boxed{-A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\rho+i\eta)]} & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix} + O(\lambda^6)$$

Large CPV Suppressed CPV

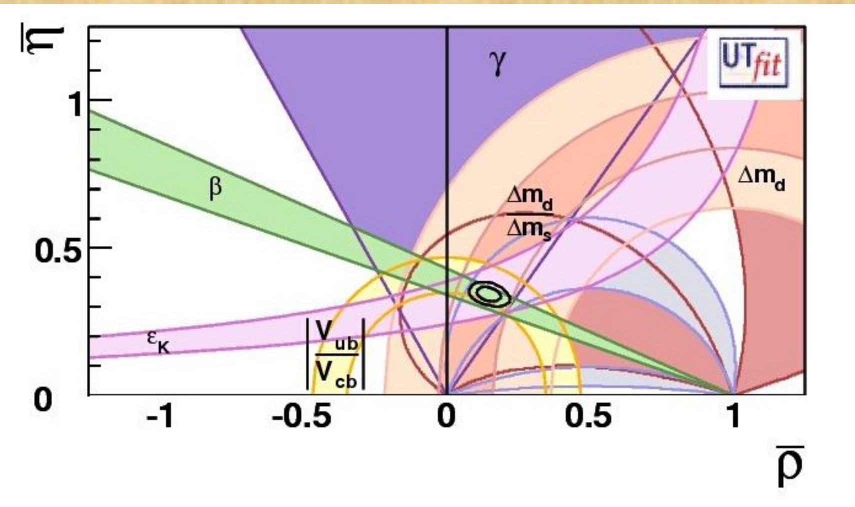


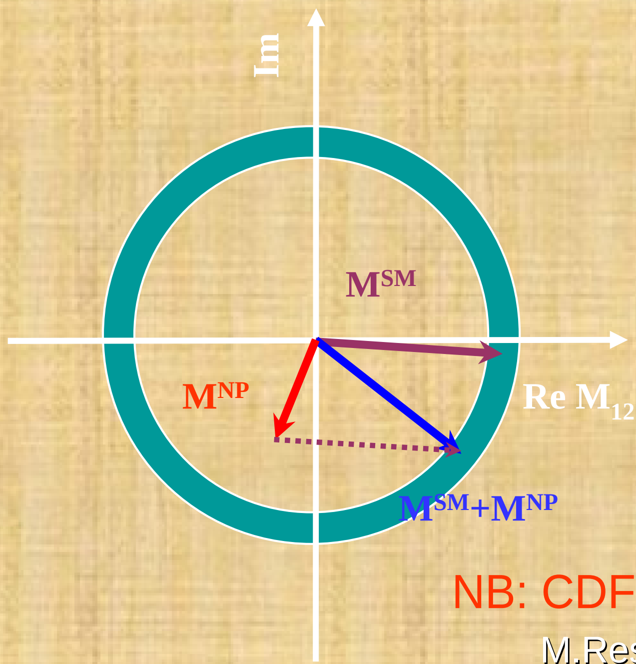
$\Rightarrow$ Standard Model does not predict values for CKM elements:

$\Rightarrow$ CKM hyerarchy implies small CP violation in B_s mixing

New Physics in B_s mixing

- New Physics could likely contribute to $\Delta B=2$ transitions
- CKM fit including $\Delta ms/\Delta md$ (unfortunately) very successful
- But the picture is not complete until also the phase has been constrained





- Phase of the mixing amplitude is poorly determined
- Both are needed to constrain New Physics:

$$\boxed{M_{12} = |M_{12}|\, e^{i\Phi_M} = |M_{12}|\, e^{-i2\beta_s}}$$

Large value of CP Violation phase Φ_M is a clear sign of New Physics!

NB: CDF and DØ use different notations $2\beta s(CDF) = -\phi_s(DØ)$

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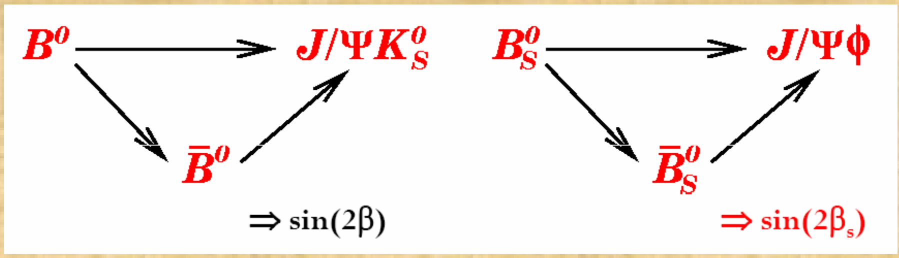
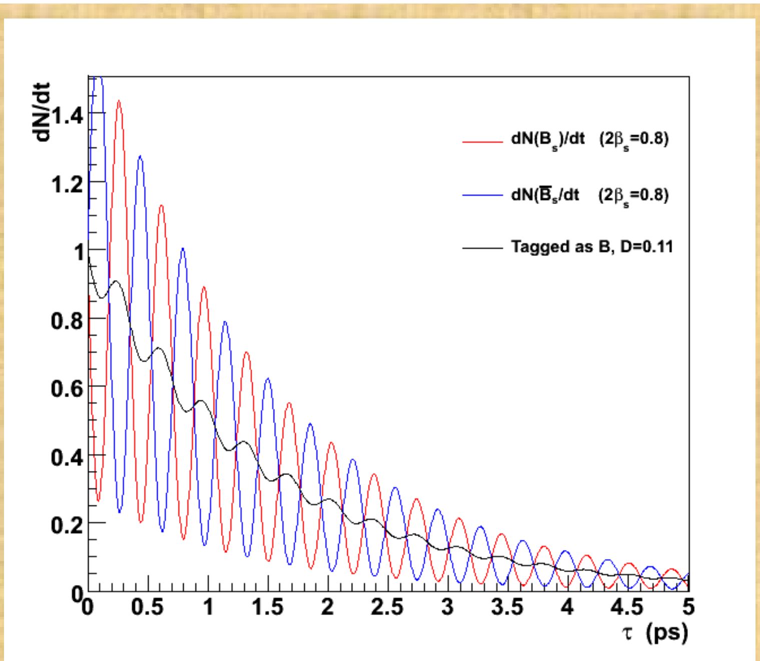
$B_s \rightarrow J/\Psi\phi$ CP Violating Decay Rate

- CP violation in interference of decay with/without mixing in Bs decays to CP eigenstate final state
  - sin2β analog



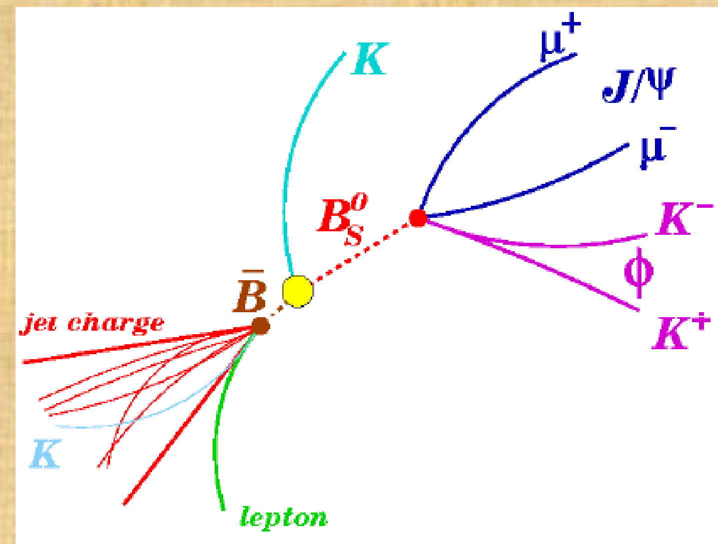
- Contrary to the sin2β case B_s mixes much faster → cannot show still the asymmetry grafically



- "Signal" appears as a time and CP dependent modulation of the exponential decay
  - In the SM the modulation is extremely tiny, the figure is exagerated
- Imperfect Tagging and experimental resolution on proper time makes life very hard
  - (typical dilution but no proper time smearing here)

- $J/\Psi\phi$ is a mixture of CP eigenstate → need to be statistically separated through angular analysis

Analysis Flow



1 Reconstruct decays from stable products:

- $B_s \rightarrow J/\Psi[\mu^+\mu^-]\ \Phi[K^+K^-]$
- $B_d \rightarrow J/\Psi[\mu^+\mu^-]\ K^{*0}[K^+\pi^-]$ (control sample)

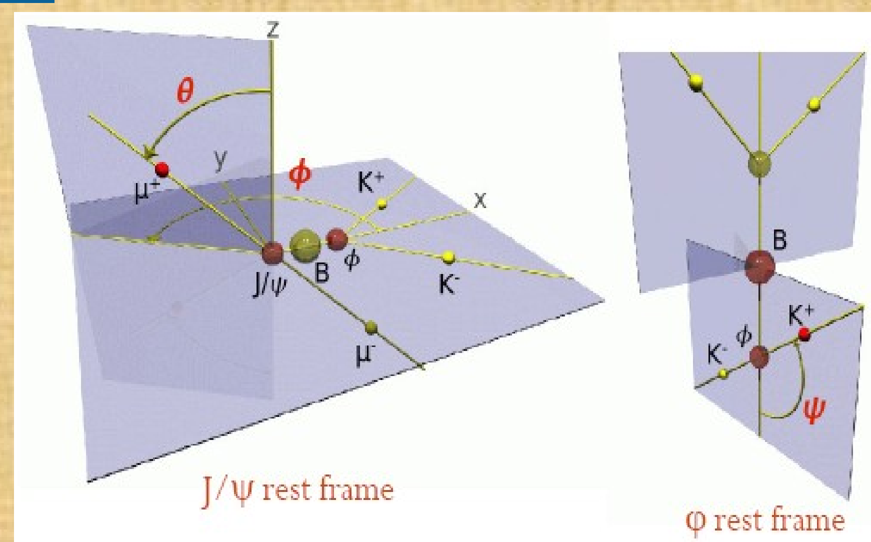
2. Measure lifetime $ct = m_B * L_{xy}/p_T$
   - Proper time resolution essential to resolve oscillations

3. Measure decay angles in transversity base:

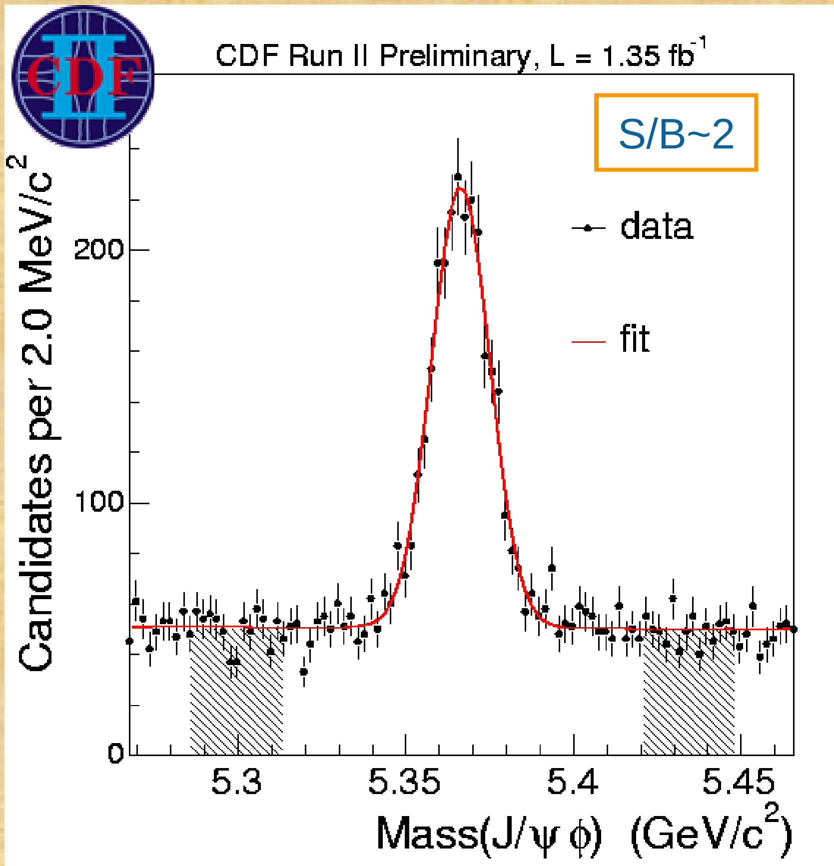
$$\vec{w} = (\theta_T, \Phi_T, \psi)$$

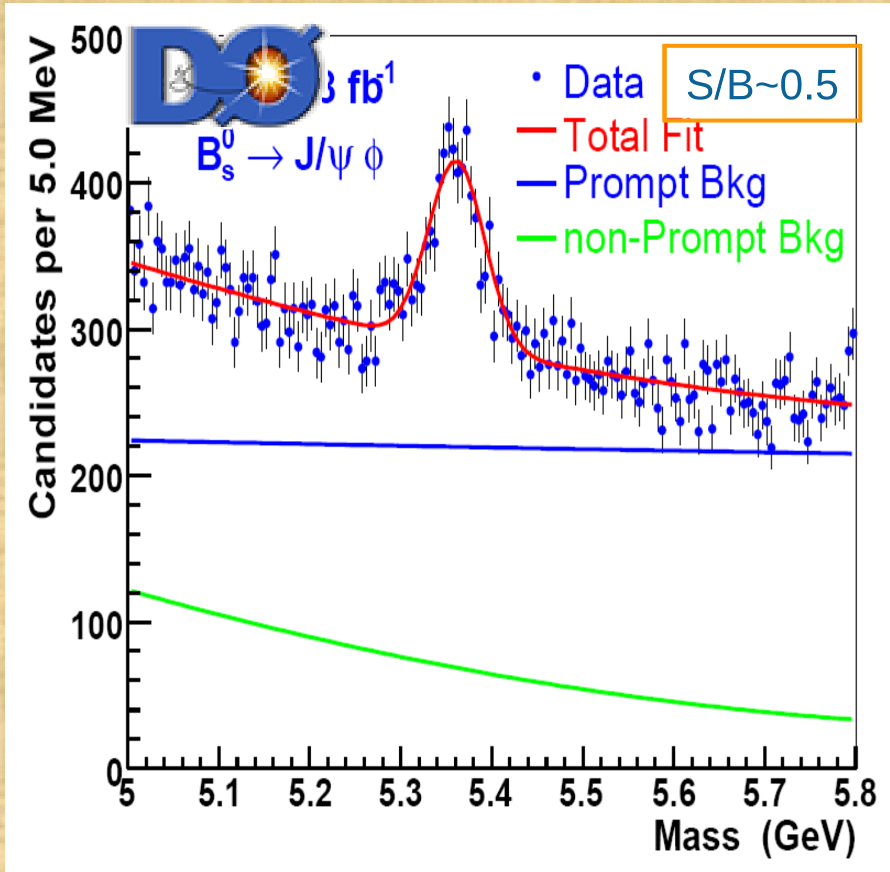
4. Identify $B_s / \bar{B}_s$ at production time:
   - Flavor Tagging (Tag decision ξ)

5. Perform maximum likelihood fit:
   - Likelihood in m, ct, w , ξ



Signal





Signal Candidates:

- ~2000 in 1.35 fb^{-1} (Tagged analysis)
- ~2500 in 1.7 fb^{-1} (Untagged analysis)

Signal Candidates:

- ~2000 in 2.8 fb^{-1} (Tagged analysis)

P→VV decay rate (I)

$$\frac{d^4P(t,\vec{w})}{dtd\vec{w}} \propto |A_0|^2 T_+ f_1(\vec{w}) + |A_\parallel|^2 T_+ f_2(\vec{w}) + |A_\perp|^2 T_- f_3(\vec{w}) + |A_\parallel||A_\perp| U_+ f_4(\vec{w}) + |A_0||A_\parallel| \cos(\delta_\parallel) T_+ f_5(\vec{w}) + |A_0||A_\perp| V_+ f_6(\vec{w})$$

CP conserving strong phases

$$\delta_\parallel = \arg(A_\parallel^* A_0)$$

$$\delta_\perp = \arg(A_\perp^* A_0)$$

- Decay rate is a function of time, decay angles $\vec{w} = (\theta_T, \Phi_T, \psi)$, initial B_s flavor and parameters $\Delta\Gamma_s$, β_s
- B_s decays into admixture of CP eigenstates (L=0,2 CP even; L=1 CP odd); 3 independent decay amplitude
- Using transverse polarization basis: A_0, $A_{//}$ CP even ; $A_\perp$ CP odd
  - interference terms allow sensitivity to CP violation in untagged (or poorly tagged) sample
- f_i (i=1,…,6) encode the different angular distributions

P→VV decay rate(II)

$$\frac{d^4P(t,\vec{w})}{dtd\vec{w}} \propto A_0|^2 T_+ f_1(\vec{w}) + |A_\parallel|^2 T_+ f_2(\vec{w})$$
$$+|A_\perp|^2 T_- f_3(\vec{w}) + |A_\parallel||A_\perp| U_+ f_4(\vec{w})$$
$$+|A_0||A_\parallel|\cos(\delta_\parallel) T_+ f_5(\vec{w})$$
$$+|A_0||A_\perp| V_+ f_6(\vec{w})$$

CP conserving strong phases

$$\delta_\parallel = \arg(A_\parallel^* A_0)$$
$$\delta_\perp = \arg(A_\perp^* A_0)$$

$$T_\pm = e^{-\Gamma t} \times [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2)]$$
$$\mp \eta \sin(2\beta_s)\sin(\Delta m_s t) \quad \eta = +1(-1) \text{ for } P(\bar{P})$$

$$U_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t)$$
$$-\cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t)$$
$$\pm\cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

$$V_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp)\cos(\Delta m_s t)$$
$$-\cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t)$$
$$\pm\cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

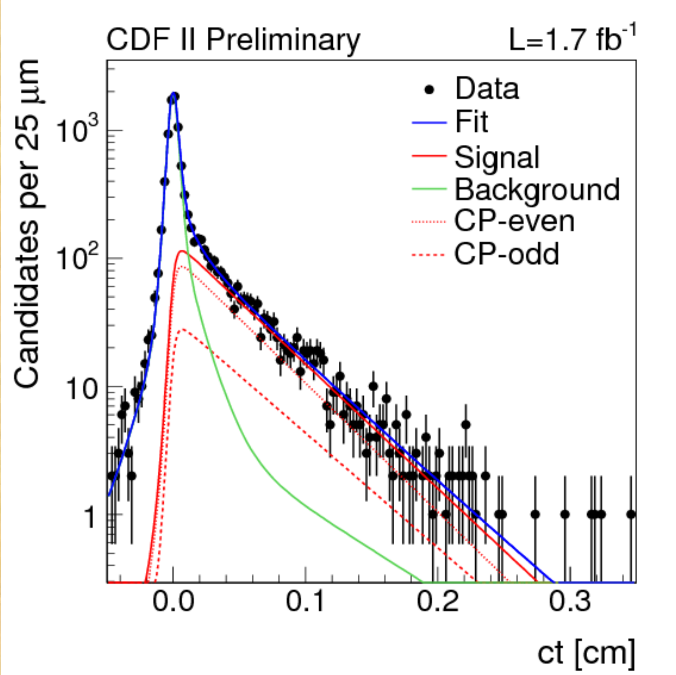
Terms with Δm_s dependence flip sign with initial B_s flavor

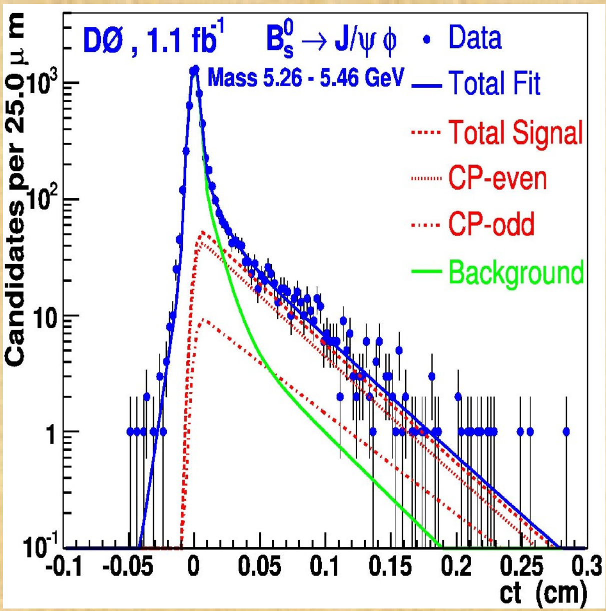
Disappear summing $B_s+\bar{B}_s$

(untagged strategy)

Sensitivity to $|\sin(2\beta_s)|$ remain in CP_{even} -CP_{odd} interference terms in triple differential decay rate

B_s average lifetime (β_s=0 case)





PRL 98, 121801 (2007)

$$\tau_s = 1.52 \pm 0.08(\text{stat})^{+0.01}_{-0.03}(\text{syst})\ \text{ps}$$

$$\Delta\Gamma_s = 0.12^{+0.08}_{-0.12}(\text{stat}) \pm 0.02(\text{syst})\ \text{ps}^{-1}$$

World Best $\Delta\Gamma_s$, Γ_s PRL 100, 121803 (2008)

Lifetime: $\tau_s = 1.52 \pm 0.04(\text{stat}) \pm 0.02(\text{syst})\ \text{ps}$

Decay Width: $\Delta\Gamma_s = 0.08 \pm 0.06(\text{stat}) \pm 0.01(\text{syst})\ \text{ps}^{-1}$

Superseeded by recent 2.8 fb^{-1} result:

$$\tau_s = 1.53 \pm 0.06(stat) \pm 0.01(syst)\ \ ps$$

$$\Delta\Gamma_s = 0.14 \pm 0.07(stat)^{+0.01}_{-0.02}(syst)\ \ ps^{-1}$$

Nicely consistent with τ_d(PDG) = 1.530± 0.009 ps

Untagged J/Ψφ result ($\beta_s \neq 0$ case)

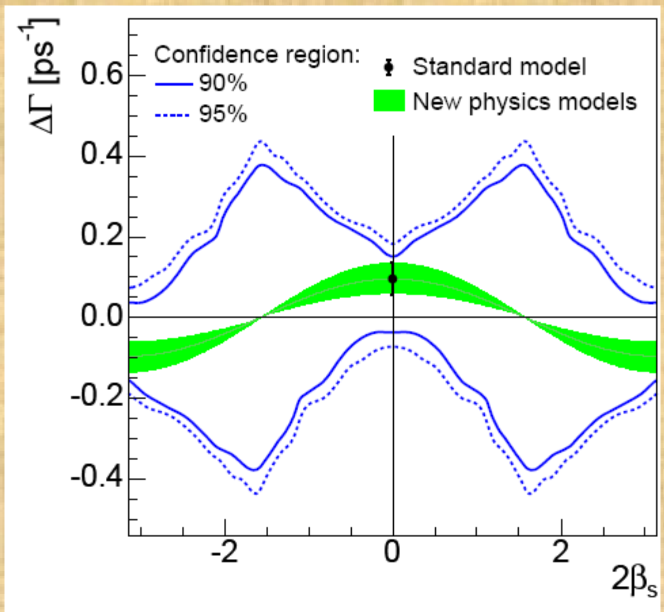
- Symmetry in the likelihood 4-fold ambiguity
- DØ quotes a point estimate:

$$\Rightarrow \quad \Phi_s = -2\beta_s = -0.79 \pm 0.56\ (\text{stat})^{+0.14}_{-0.01}\ (\text{syst})\ \text{rad}$$
$$\Rightarrow \quad \Delta\Gamma_s = 0.17 \pm 0.09\ (\text{stat}) \pm 0.02\ (\text{syst})\ \text{ps}^{-1}$$

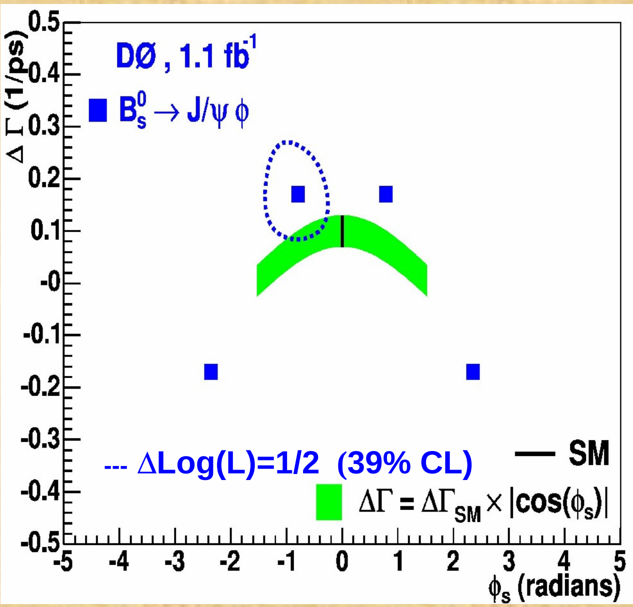
- CDF observes irregular likelihood and biases in fit

⇒ Feldman-Cousins confidence region: SM probability p_{value}=22% (1.2σ)

PRL 100, 121803 (2008) [arXiv:0712.2348]



PRL 98, 121801 (2007)



Flavor Tagging

Opposite Side Tagging

- Soft Lepton Taggers
- Jet Charge Tagger

OST's perform identically in $B_{u,d,s}$:
Calibrated in high statistics B^+/B^0 data

- Combined Performance:

✓Efficiency: $\varepsilon = 0.96 \pm 0.01$
✓Average Dilution: $D = 0.11 \pm 0.02$

Same Side Kaon Tagging

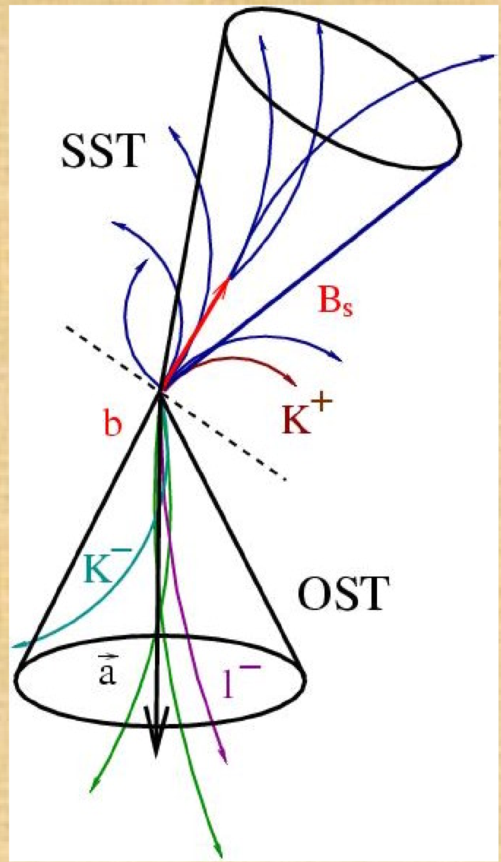
- Most powerful tagger available:

✓2–3 times more effective than combined OST

SSKT is different for B^0, B^+ and B_s:
SST needs to rely on MC simulation

- Performance:

✓Efficiency: $\varepsilon = 0.50 \pm 0.01$
✓ Average Dilution: $D = 0.27 \pm 0.04$



OST and SST combined independently
Overall $\varepsilon D^2 \sim 4\%$

DØ performance similar:
$D \sim 0.21$ $\varepsilon \sim 1$

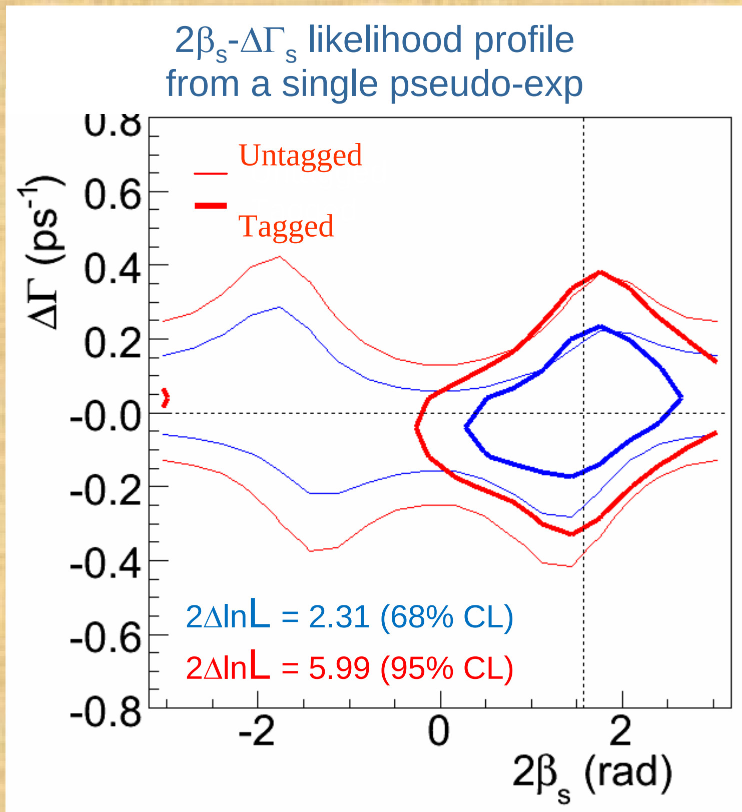
Introducing of Flavor tagging

$$2ß_s \to p - 2ß_s$$
$$\Delta G_s \to - \Delta G_s$$
$$d_{\parallel} \to 2p - d_{\parallel}$$
$$d_{\perp} \to p - d_{\perp}$$

- Tagging improves sensitivity to CP violation phase β_s (provided oscillation can be resolved)
- Removes two of the 4-fold ambiguity
- Still two exact mirror solution due to strong phase ambiguity remain

  - Likelihood: with tagging, gain sensitivity to both $|\cos(2b_s)|$ and $\sin(2b_s)$, rather than only $|\cos(2b_s)|$ and $|\sin(2b_s)|$ (note absolute value)
  - $\beta_s \leftrightarrow -\beta_s$ no longer a symmetry thanks to $\sin(\Delta m_s t)$ terms:

    $\Rightarrow$ 4-fold ambiguity reduced to <u>2-fold</u>



CDF result

PRL 100, 161802 (2008)
arXiv:0712.2397 [hep-ex]

Perform an unbinned maximum likelihood fit to mass, ct and angles: 27 parameters total !

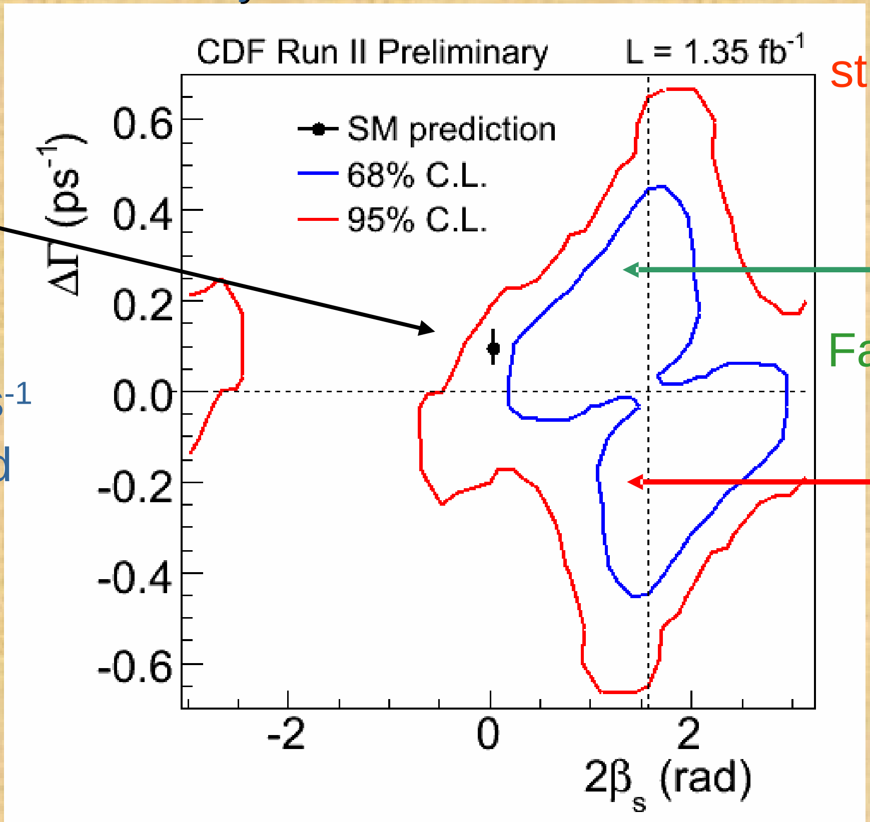
- Symmetries of the problem and low statistics means the likelihood contour does **not** have the correct coverage.
- Quoted confidence region is based on a modified Feldman Cousin profile-likelihood ratio ordering with inclusion of systematic uncertainties.

Standard Model expectations:

arXiv:hep-ph/0612167

$\Delta\Gamma_s = 0.096 \pm 0.039\ ps^{-1}$

$2\beta_s = 0.04 \pm 0.01$ rad



strong phases ambiguity:

$\cos(\delta_\perp) < 0$
$\cos(\delta_\perp - \delta_\parallel) > 0$

Favored by factorization and B_d analog

$\cos(\delta_\perp) > 0$
$\cos(\delta_\perp - \delta_\parallel) < 0$

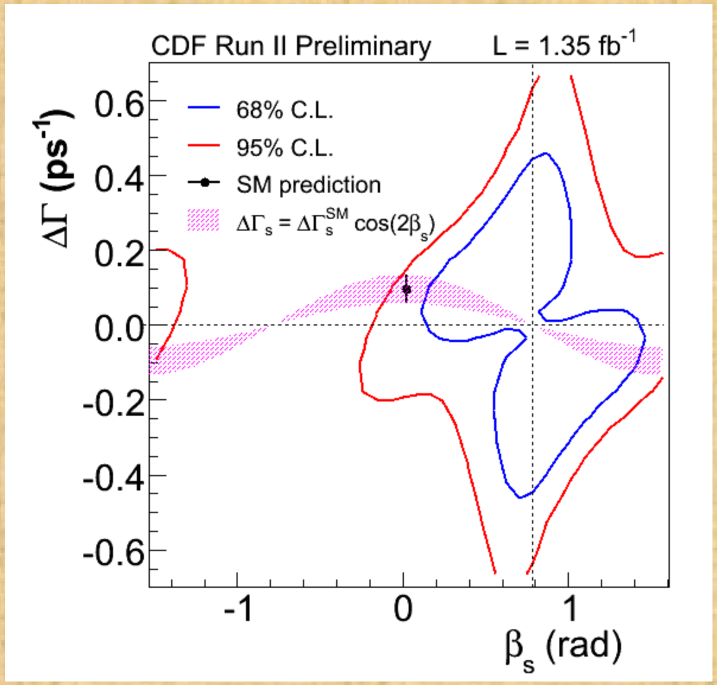
Standard Model p_{value} = 15% (1.5σ)

Adding information/Theory

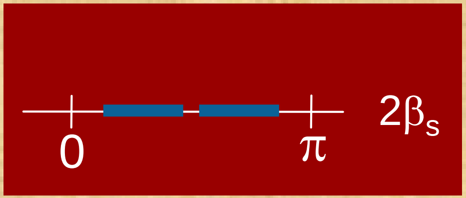
$\Delta\Gamma_s$ is theoretically constrained:

- Input $\Delta\Gamma_s = 2|\Gamma_{12}|\cos\Phi_s \approx 2|\Gamma_{12}|\cos(2\beta_s)$:

[Γ_{12}=0.048±0.018 - Nierste, Lenz, hep-ph/0612167]

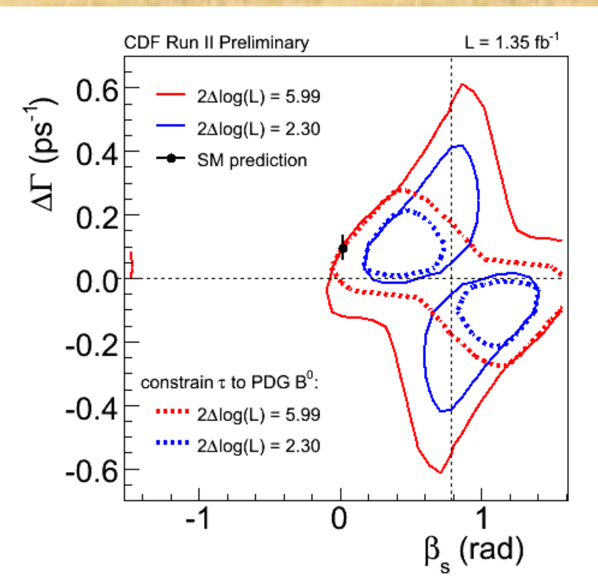


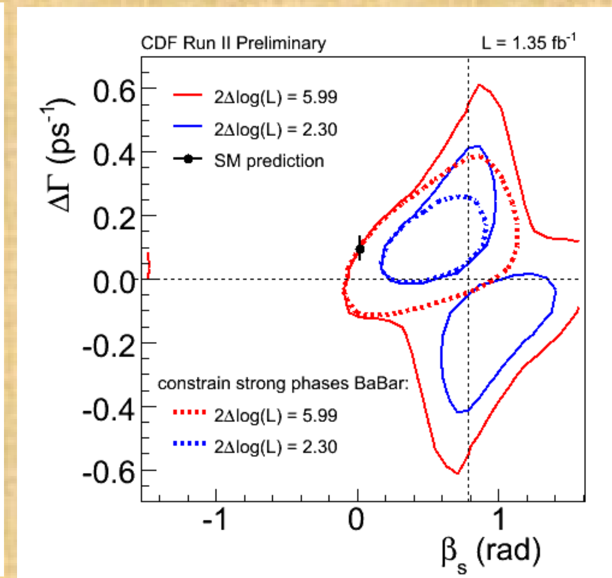
$2\beta_s$ in [0.24, 1.36] U [1.78, 2.90] at 68% C.L.

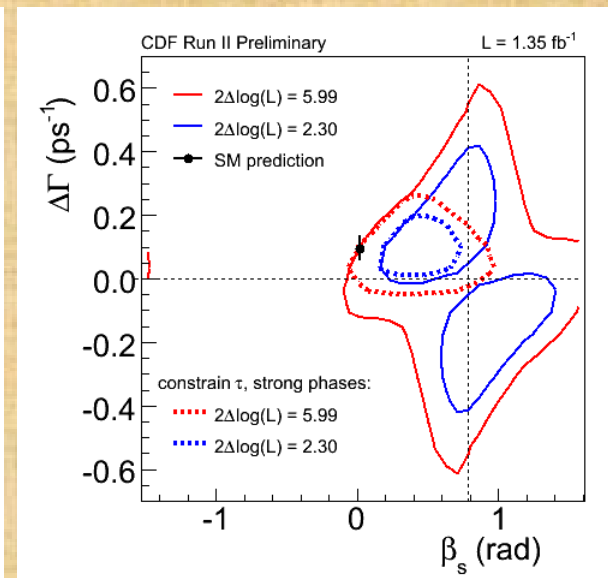


Adding information/Lifetime and strong phase constraints

- Contraint $\tau_s = \tau_d \pm 1\%$
- Constraint strong phase to $B_d \rightarrow J/\psi\ K^*$
- Both

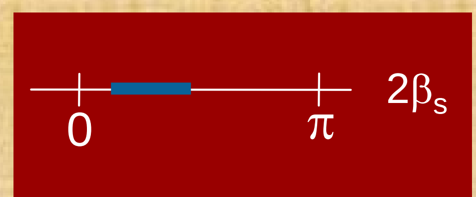






- Largest effect on $\Delta\Gamma_s$,and near $\beta_s = \pi/4$,likelihood near $\beta_s = 0$ not very sensitive (too bad)

$2\beta_s$ in [0.40, 1.20] at 68% C.L.



DØ Result

arXiv: 0802.2255 [hep-ex]

- **DØ:** ~2000 B_s events with 2.8 fb^{-1}
- Assume strong phase as measured in $B_d \to J/\Psi K^*$ decays
- Combined Tagging Power $\Rightarrow \varepsilon D^2 = (4.68 \pm 0.54)\%$ (NEW)

$$\tau_s = 1.52 \pm 0.06 \ (stat) \pm 0.01 \ (syst) \ ps$$

$$\Delta\Gamma_s = 0.19 \pm 0.07 \ (stat)^{+0.02}_{-0.01} \ (syst) \ ps^{-1}$$

$$\Phi_s = -2\beta_s = -0.57^{+0.24}_{-0.30} \ (stat)^{+0.07}_{-0.02} \ (syst) \ rad$$

FIT inputs:

Δm_s fixed to 17.77 ps^{-1}

Gaussian constraint on Strong phases:

$\delta_\perp - \delta_\parallel = -0.46 \pm (\pi/5)$

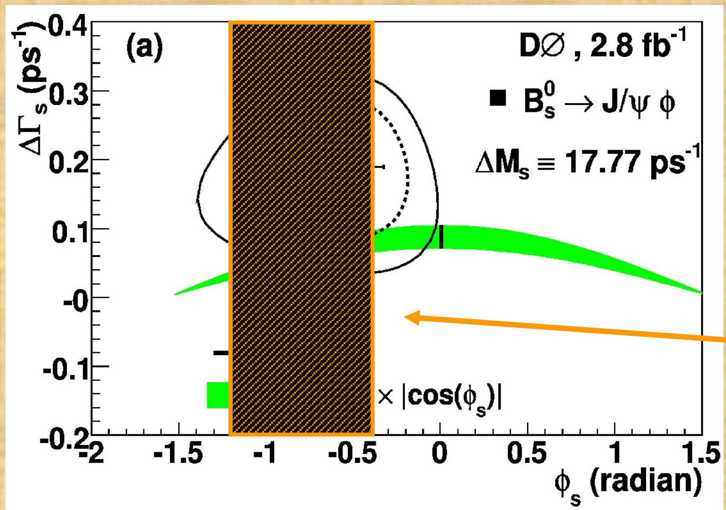
$\delta_\perp = +2.92 \pm (\pi/5)$

Standard Model expectations:

(arXiv:hep-ph/0612167)

$\Phi_s = -0.04 \pm 0.01$ rad

Standard Model p_{value} = 6.6%



90% C.L. contours:

$-1.20 < 2\beta_s < 0.06$ rad

$0.06 < \Delta\Gamma_s < 0.30$ ps^{-1}

CDF 68% CL:

Constraining lifetime, strong phases and $\Delta\Gamma_s$

Additional ϕ_s related measurement at TeVatron and impact on New Physics

B_s Semileptonic Asymmetry

- if M_{12}/Γ_{12}>>1

$$A^s_{SL} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan \Phi_s$$

- **D∅:** 1.3 fb^{-1} of data collected (B_s semileptonic decays):

$$A^s_{SL} = [2.45 \pm 1.93\ (stat) \pm 0.35\ (syst)]\ \text{x}\ 10^{-2}$$

PRL 98, 151801 (2007)

- **CDF:** 1.6 fb^{-1} of data collected (dimuon charge asymmetry):

$$A^s_{SL} = 0.020 \pm 0.021\ (stat) \pm 0.016\ (syst) \pm 0.009\ (inputs)$$

(http://www-cdf.fnal.gov/physics/new/bottom/070816.blessed-acp-bsemil/)

- **D∅:** 1.0 fb^{-1} of data collected (dimuon charge asymmetry):

$$A^s_{SL} = -0.0064 \pm 0.0101\ (stat + syst)$$

PRD 74, 092001 (2006)

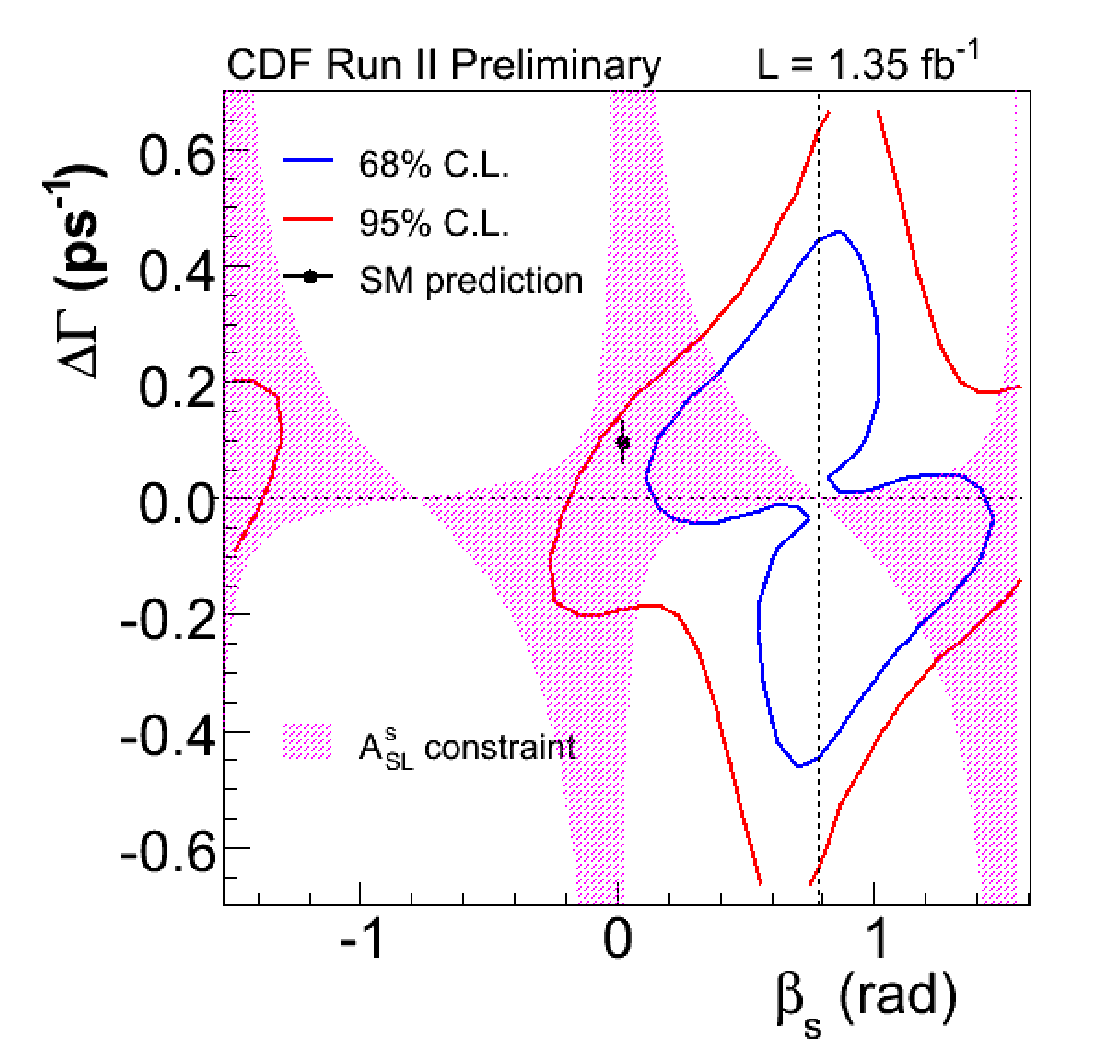
- **Unofficial Tevatron combination:** using common/updated inputs

$$A^s_{SL} = -0.0054 \pm 0.0072\ (stat + syst)$$

$$A^s_{SL}(SM) = O(10^{-5})$$

  - Quite precise, compare with $A^d_{SL} = -0.0005 \pm 0.0055\ (stat + syst)$

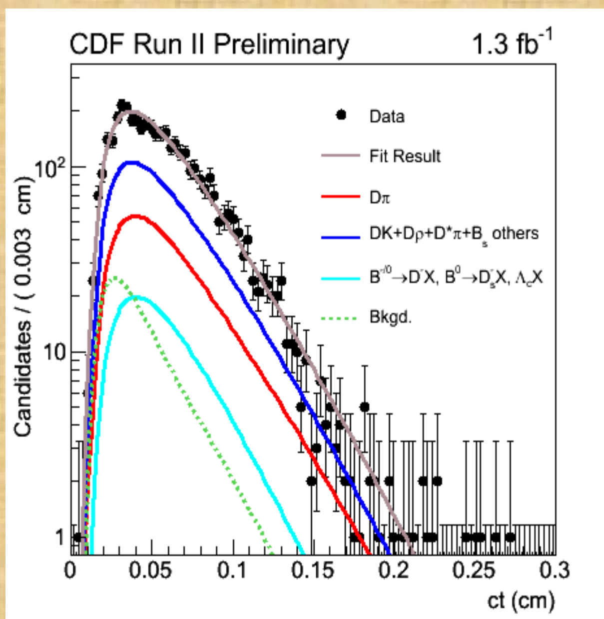
ASL_s constraint

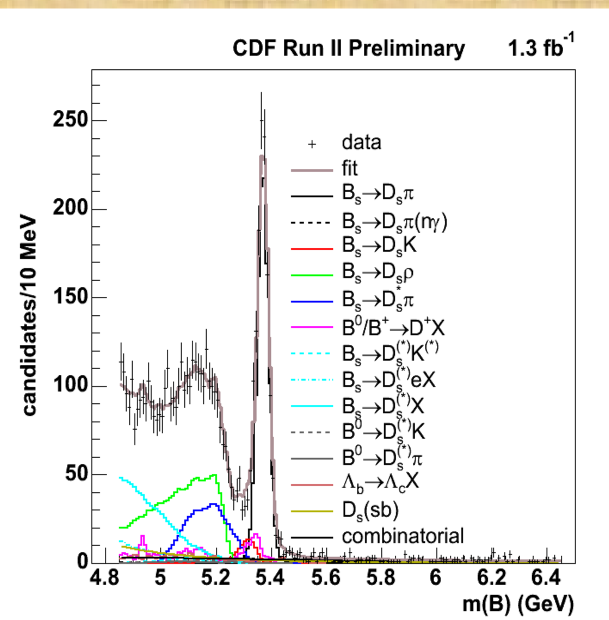


Flavor specific lifetime constraint

- Flavor specific modes: only accessible from either B_s or anti-B_s state
- Light and Heavy state contributes both 50% to the time evolution
- Fit to a single lifetime determine τ_{fs}
  - Expected higher than $1/\Gamma_s$
  - HQET : $\Gamma_s = \Gamma_d \pm O(1\%)$

$$\tau_{fs} = \frac{1}{\Gamma_s} \frac{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$



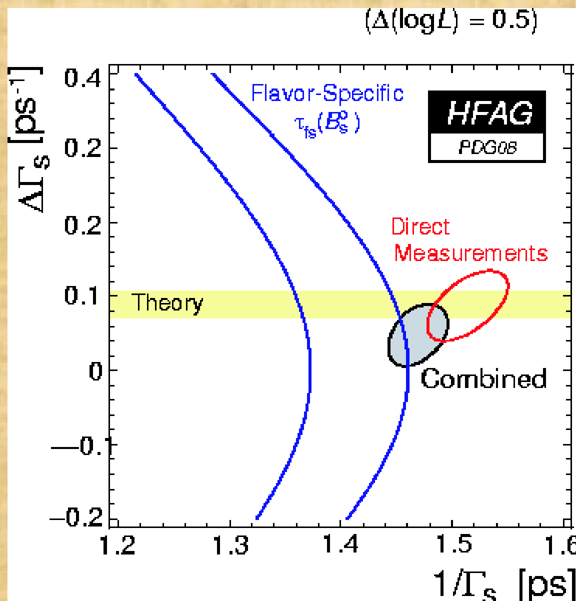


- Recent high precision measurement from CDF using $B_s \rightarrow D_s^{(*)}\pi$+ $D_s^{(*)}\pi$+ $D_s\rho$ final states using 1.3 fb-1
- $c\tau(B_s)$ = 455.0 ± 12.2 (stat.) ± 7.4 (syst.) μm

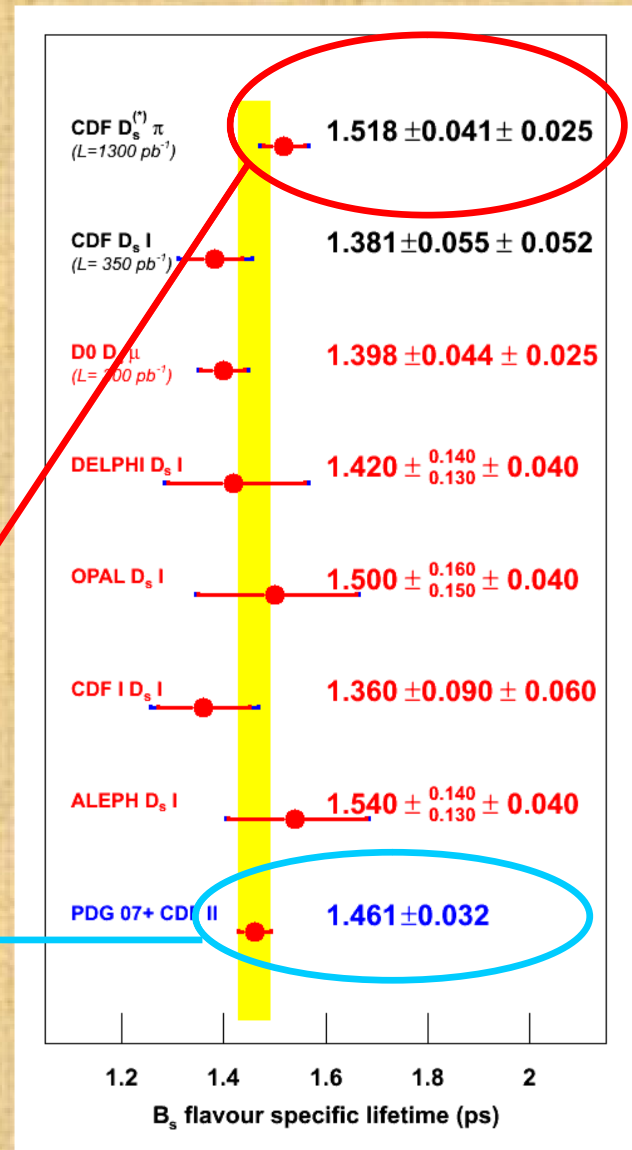
www-cdf.fnal.gov/physics/new/bottom/080207.blessed-bs-lifetime

Flavor specific lifetime constraint

- PDG 08 average: 1.417 ± 0.042 ps
- Slightly lower than recent τ_s from $B_s \rightarrow J/\Psi\phi$ (1.52±0.04 ps) and τ_d

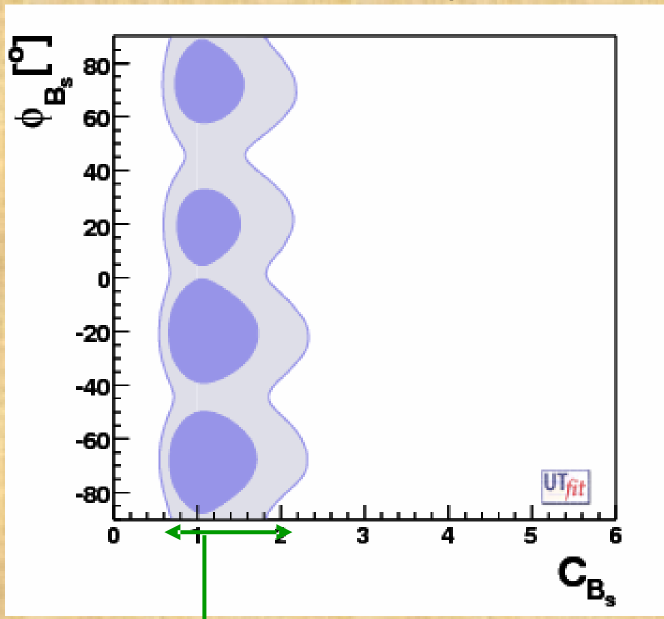


- CDF hadronic more consistent
- Naïve average PDG07+CDFII
- Current precision on τ_{fs} can be translated in a constraint on $\Delta\Gamma_s < 0.16\ ps^{-1}$ at 1 σ



NP in Bs mixing

pre tagged J/$\Psi\phi$ status



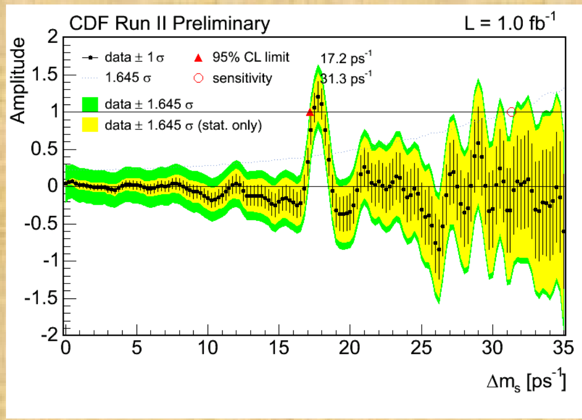
UT$_{fit}$ inputs:

Δm_s measurement (CDF)
Lifetime τ_s (CDF and D∅)
$\Delta\Gamma_s$ (CDF on 200 pb^{-1})
$\Delta\Gamma_s$ and Φ_s (D∅ on 1.1 fb^{-1})
Semileptonic A_{SL} (D∅)

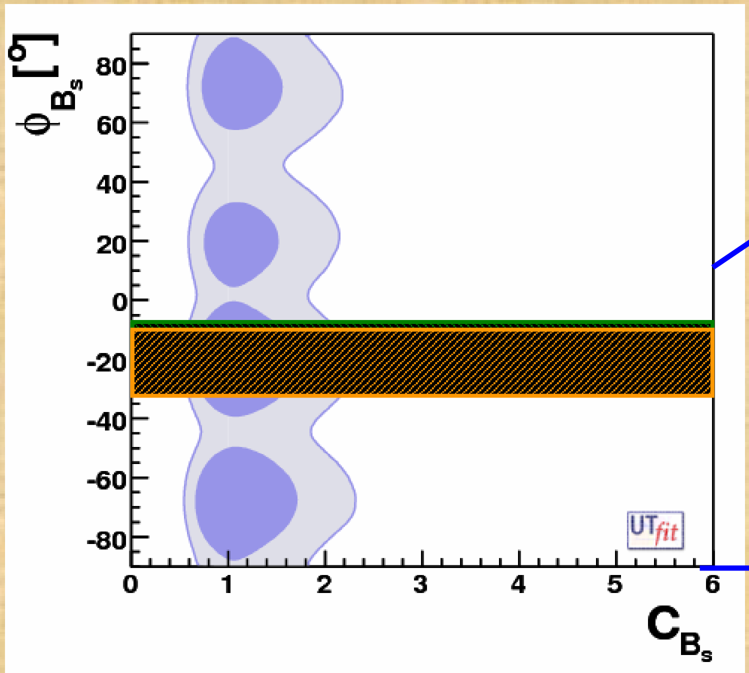
$\Delta m_s = C_{Bs} * \Delta m_s^{SM}$: Lattice-QCD dominated uncertainty

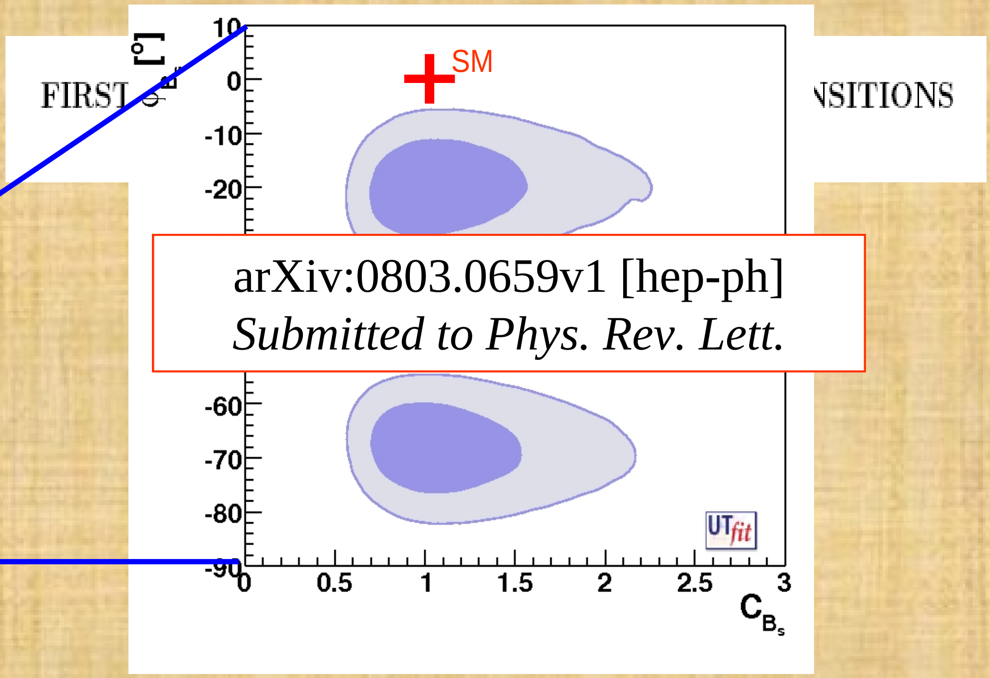
$$\frac{\langle B_s | H_{eff}^{full} | \bar{B}_s \rangle}{\langle B_s | H_{eff}^{SM} | \bar{B}_s \rangle} = \boxed{C_{Bs}}\, e^{2i\,\boxed{\Phi_{Bs}}}$$

$\beta_s = \beta_s^{SM} - \Phi_{Bs}$: Experimentally dominated uncertainty



Effects of recent measurements





arXiv:0803.0659v1 [hep-ph]
Submitted to Phys. Rev. Lett.

Constraint:

✓ $\Delta\Gamma_s = 2|\Gamma_{12}|\cos\Phi_s \approx 2|\Gamma_{12}|\cos(2\beta_s)$
with (Γ_{12}=0.048±0.018):

✓Strong phases from J/Ψ K^{*0} [hep-ex/0411016], B_d lifetime [PDG] and $\Delta\Gamma_s \approx 2|\Gamma_{12}|\cos(2\beta_s)$:

CDF: $2\beta_s \in$ [0.40, 1.20] @ 68% C.L

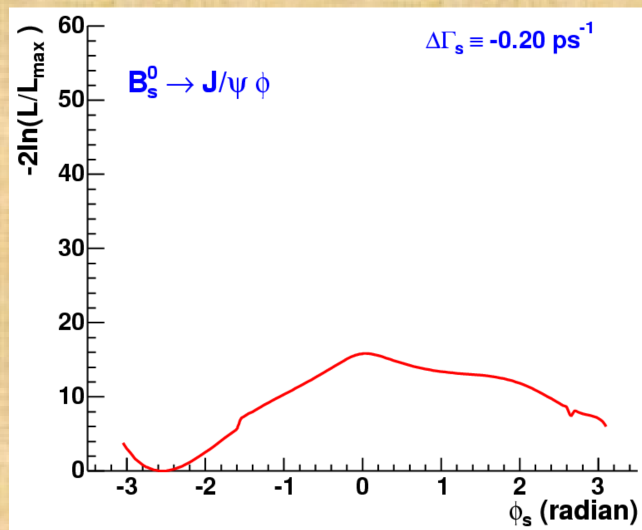
DØ: $2\beta_s = +0.46 \pm 0.28$

UTfit conclusions:

✓ NP phase 3σ from 0 (~-20°) with some approximation in the treatment of experimental result has been used

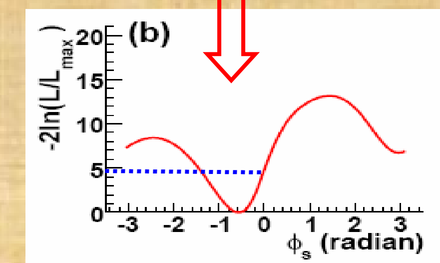
TeVatron experiments working towards a combination without approximations @ ICHEP

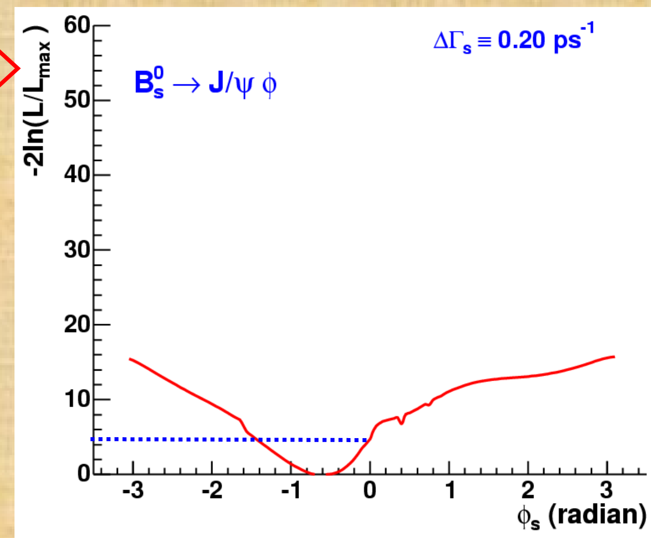
Tevatron Combination (very preliminary)

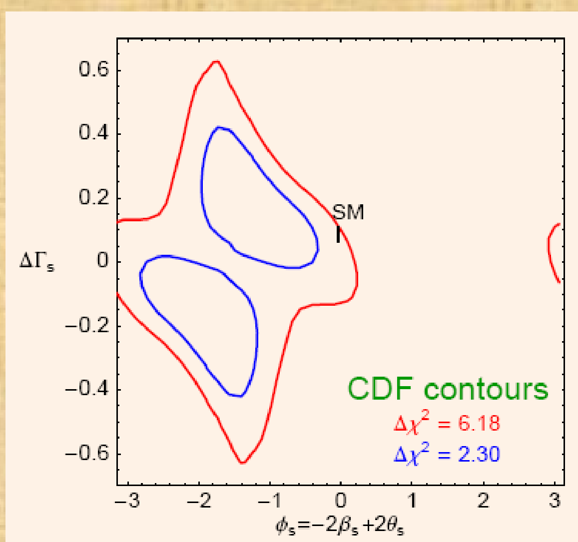


w/o strong phase constraint

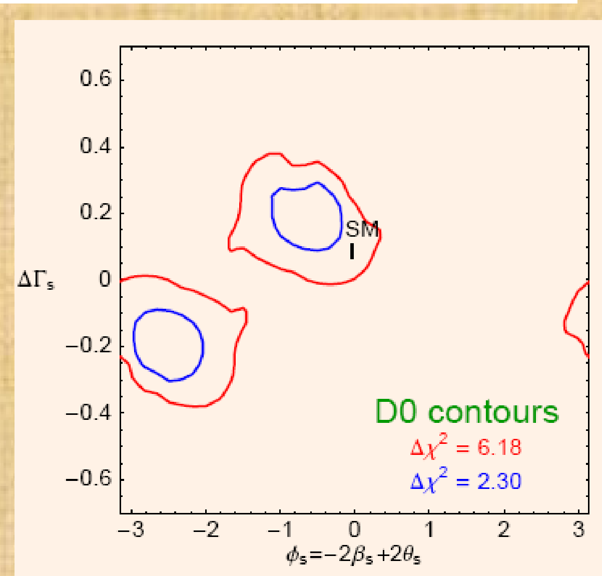
Default fit



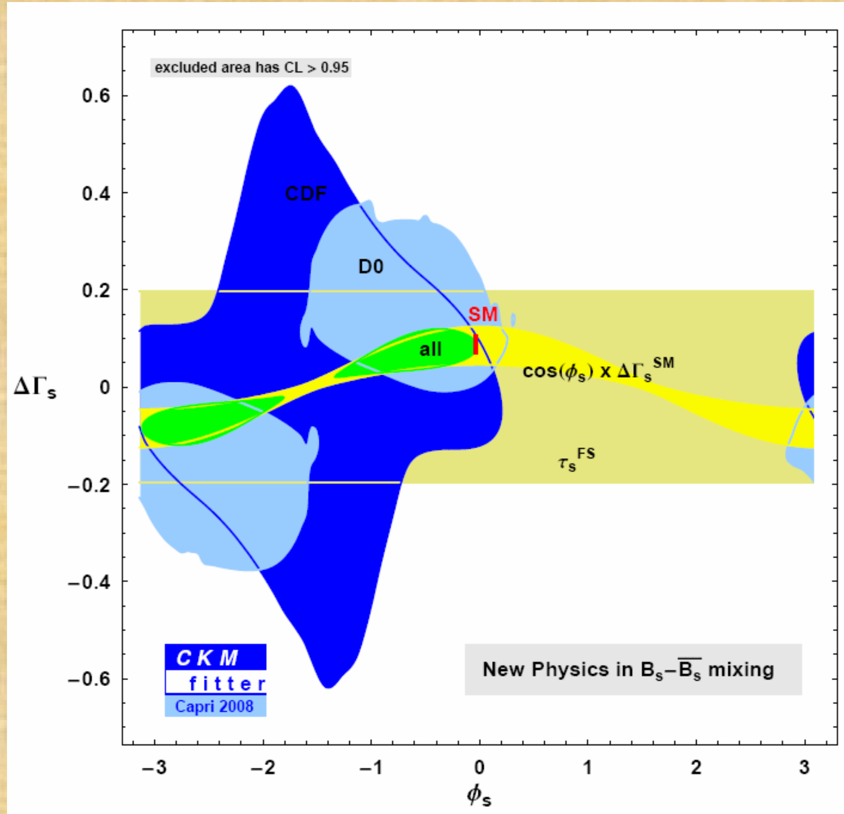


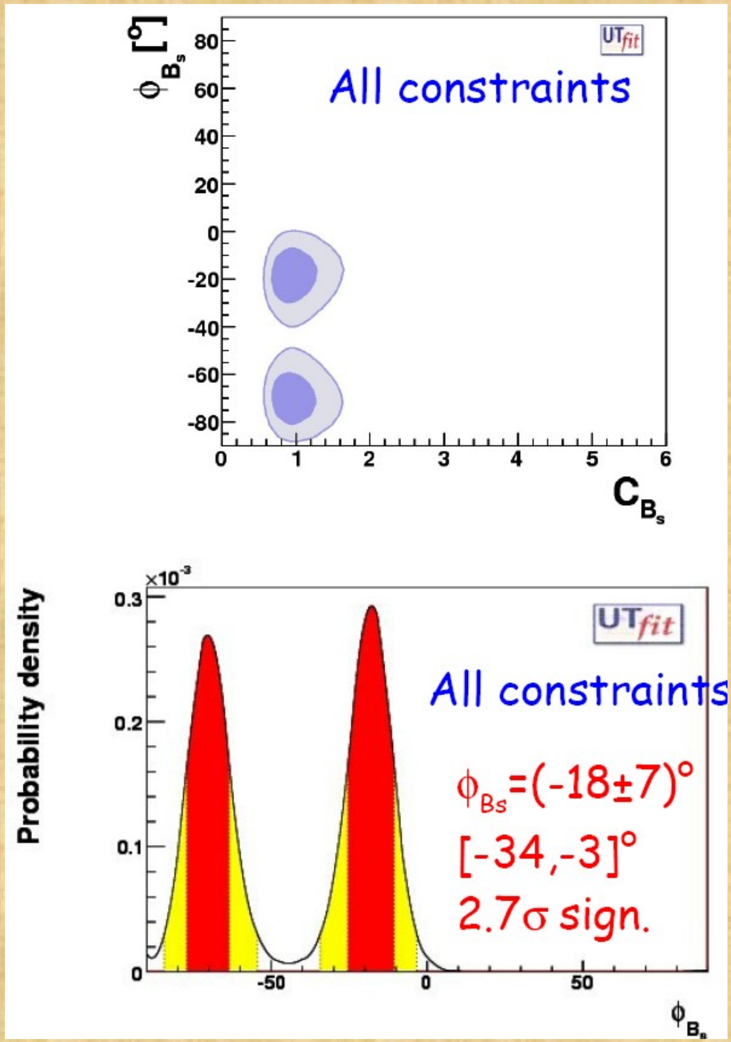


- First step towards a TeVatron combination, remove strong phase constraint in DØ fit !
- HFAG combination at ICHEP



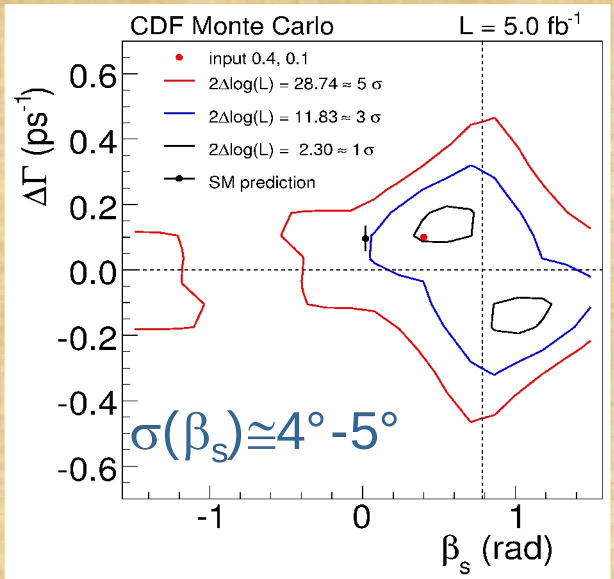
From Capri to Trieste

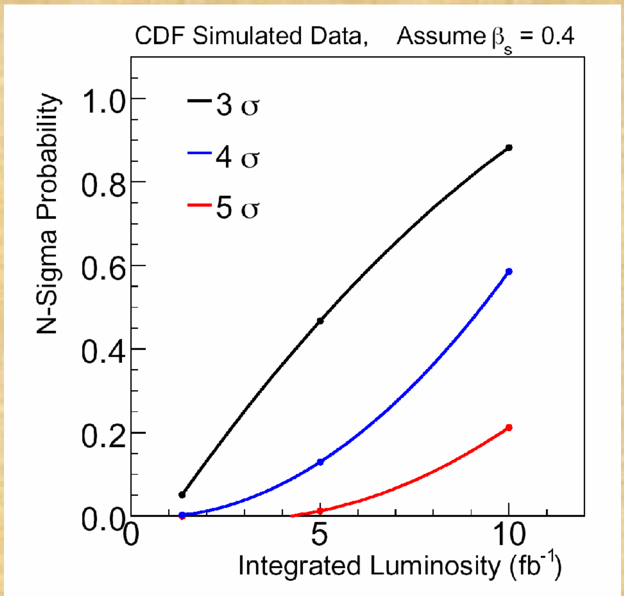




- CKMfitter full fit 2.5 σ from SM
- UTfit full fit 2.5 σ from SM
- Bayesian magic?
  - DØ unconstrained fit!

Tevatron Outlook



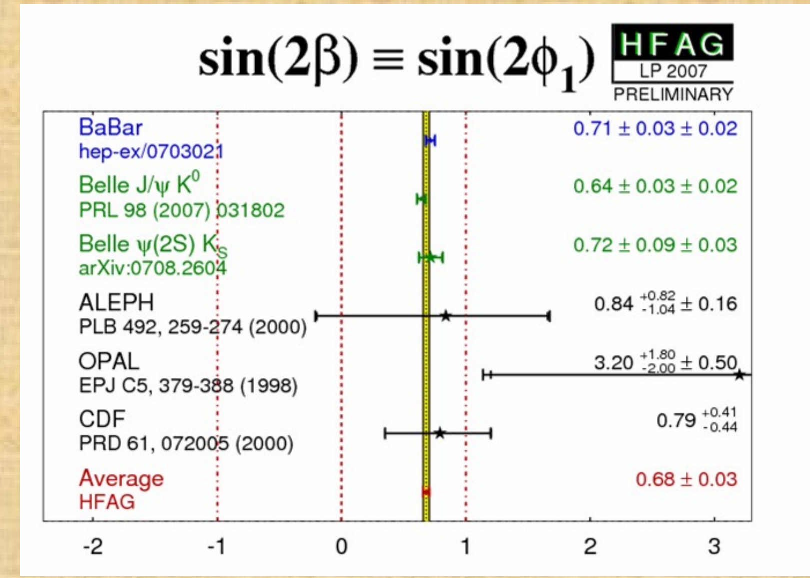


- With no analysis improvements, and no external constraints, but same signal yield and experimental resolution:
  - With 5(10) fb^{-1}each Tevatron experiment could reach a 3(5) σ significance if "fluctuation" is real
  - 10 fb^{-1} may also be viewed as a CDF+D0 combination with 5fb^{-1}
  - Expect >6 fb^{-1}/experiment if TeVatron stops in 2009 and ~8 fb^{--1}/ experiment if 2010 running approved
- May do better adding further signals (triggers) or better tagging (underway)

Conclusions

- B(s) physics program at TeVatron very rich and still promising:
- Study Direct CP violation in $B_{d,u}$, B_s and Λ_b
- First ever flavor tagged measurement of $J/\Psi\phi$ rates this winter from Tevatron
  - Observe a (not yet) significant fluctuation towards large value of $\sin(2\beta_s)$
  - Make B_s physics program at the Tevatron and LHCb even more intriguing
  - CDF update with >2* statistics and DØ without constraints underway → TeVatron average

Conclusions

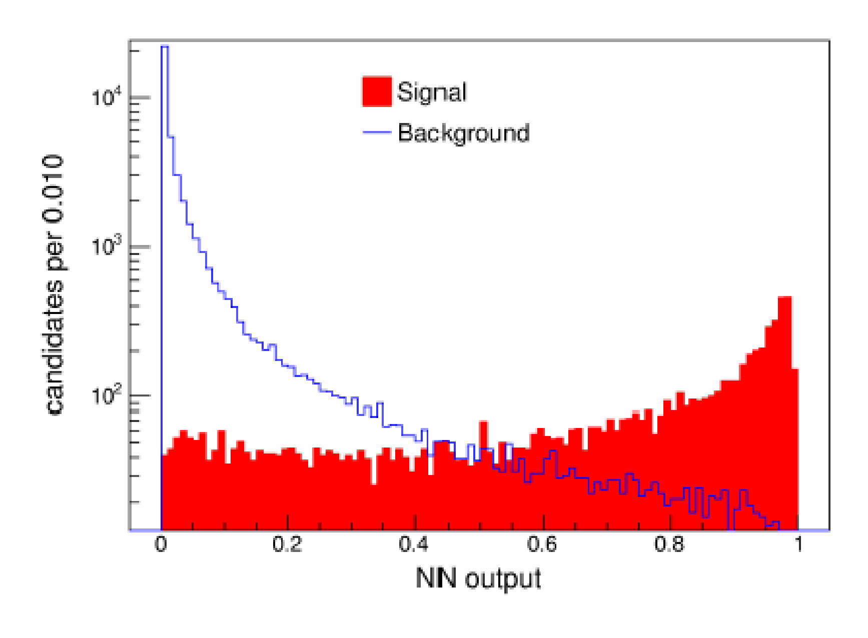


- Would be really nice to repeat 1999/2000 situation for sin2β!

Backup Slides

Trigger/Signal selection

- Trivial (?) trigger:
  - Dimuons with invariant mass cuts around J/Ψ mass:
    - $P_{t\mu}$>1.5 GeV at low luminosity
    - Increasingly restrictive at higher luminosity
  - Significant bandwidth needed at high lumi (2E32 $cm^{-2}s^{-1}$)
    - 5 KHz (L1), 100 Hz (L2), 10 Hz (3)
- Offline selection:
  - CDF: Neural Network selection
  - DØ: cut based selection



NN Variables:

B_s: p_T and vertex quality

J/Ψ: p_T and vertex quality

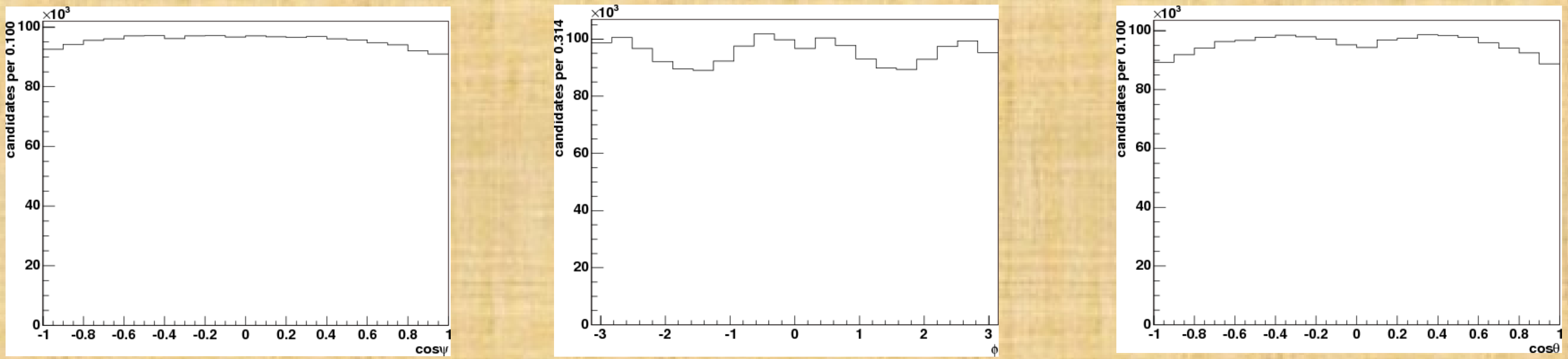
F: mass and vertex quality

K^+/K^-: p_T and PID (TOF, dE/dx)

Angular acceptance

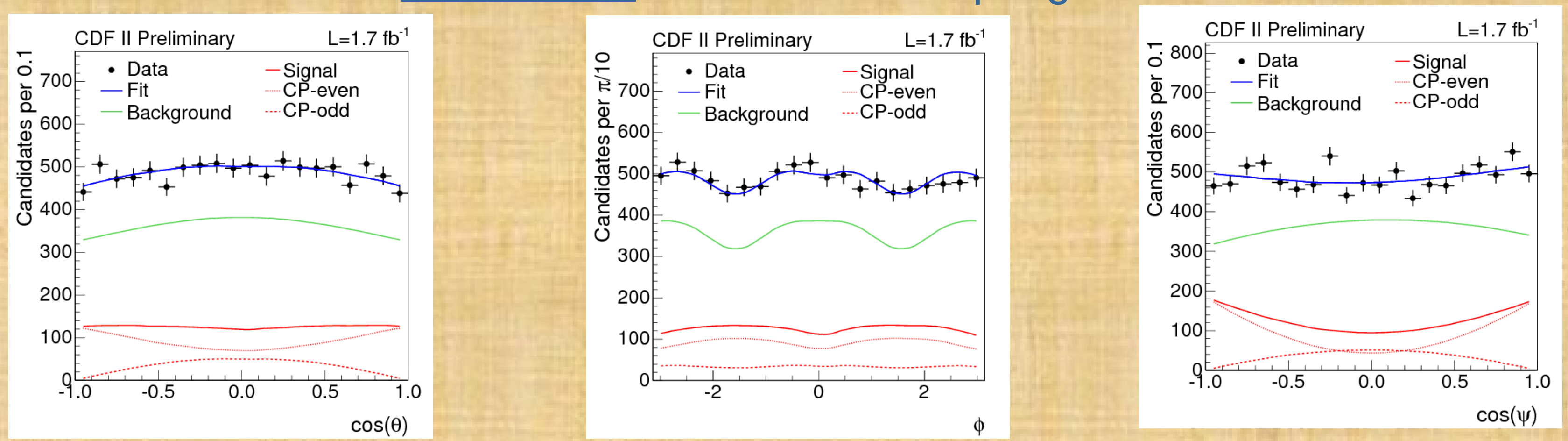
- Monte Carlo used to determine acceptance in transversity angles, two different approaches attempted: a) fitting to analytical model b) binned acceptance. Obtained equivalent results.

Acceptance



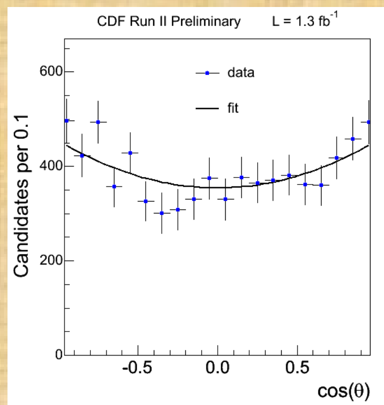
uncorrected for detector sculpting

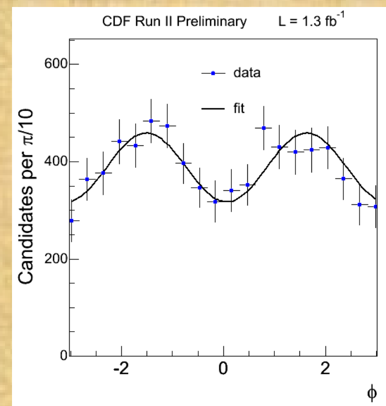
Data Fit Projections

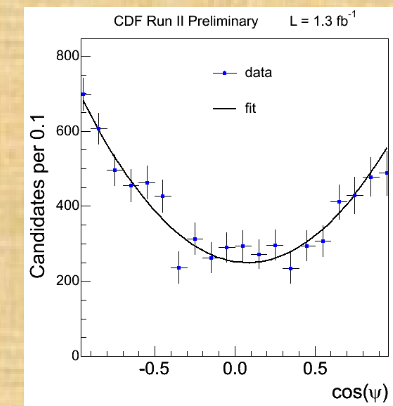


Polarization in $B_d \rightarrow J/\Psi K^{*0}$

- Acceptance corrected fit projections validates treatment of detector acceptance!







- Results for $B^0 \rightarrow J/\Psi\ K^{*0}$ in good agreement with BaBar, competitive uncertainties!

CDF
www-cdf.fnal.gov/physics/new/bottom/070830.blessed-BdPsiKS

$$ct = 456 \pm 6\ (stat) \pm 6\ (syst)\ \mu m$$

$$|A_0(0)|^2 = 0.569 \pm 0.009\ (stat) \pm 0.009\ (syst)$$

$$|A_{\parallel}(0)|^2 = 0.211 \pm 0.012\ (stat) \pm 0.006\ (syst)$$

$$\delta_{\parallel} = -2.96 \pm 0.08\ (stat) \pm 0.03\ (syst)$$

$$\delta_{\perp} = +2.97 \pm 0.06\ (stat) \pm 0.01\ (syst)$$

Babar:
Phys. Rev. D 76, 031102 (2007)

$$|A_0(0)|^2 = 0.556 \pm 0.009\ (stat) \pm 0.010\ (syst)$$

$$|A_{\parallel}(0)|^2 = 0.211 \pm 0.010\ (stat) \pm 0.006\ (syst)$$

$$\delta_{\parallel} = -2.93 \pm 0.08\ (stat) \pm 0.04\ (syst)$$

$$\delta_{\perp} = +2.96 \pm 0.05\ (stat) \pm 0.03\ (syst)$$

Bd/Bs polarization

CDF II

$$\tau = 1.52 \pm 0.04 \pm 0.02 \text{ ps},$$
$$\Delta\Gamma = 0.076^{+0.059}_{-0.063} \pm 0.006 \text{ ps}^{-1},$$
$$|A_0|^2 = 0.531 \pm 0.020 \pm 0.007,$$
$$|A_\perp|^2 = 0.239 \pm 0.029 \pm 0.011,$$
$$|A_\parallel|^2 = 0.230 \pm 0.026 \pm 0.009.$$

DØ

	free ϕ_s	$\phi_s \equiv \phi_s^{SM}$	$\Delta\Gamma_s^{th}$
$\overline{\tau}_s$ (ps)	1.52±0.06	1.53±0.06	1.49±0.05
$\Delta\Gamma_s$ (ps^{-1})	0.19±0.07	0.14±0.07	0.083 ± 0.018
$A_\perp(0)$	0.41±0.04	0.44±0.04	0.45±0.03
$\lvert A_0(0)\rvert^2 - \lvert A_\parallel(0)\rvert^2$	0.34±0.05	0.35±0.04	0.33±0.04
δ_1	−0.52±0.42	−0.48±0.45	−0.47±0.42
δ_2	3.17±0.39	3.19±0.43	3.21±0.40
ϕ_s	$-0.57^{+0.24}_{-0.30}$	$\equiv -0.04$	-0.46 ± 0.28
ΔM_s (ps^{-1})	$\equiv 17.77$	$\equiv 17.77$	$\equiv 17.77$

Babar:
Phys. Rev. D 76, 031102 (2007)

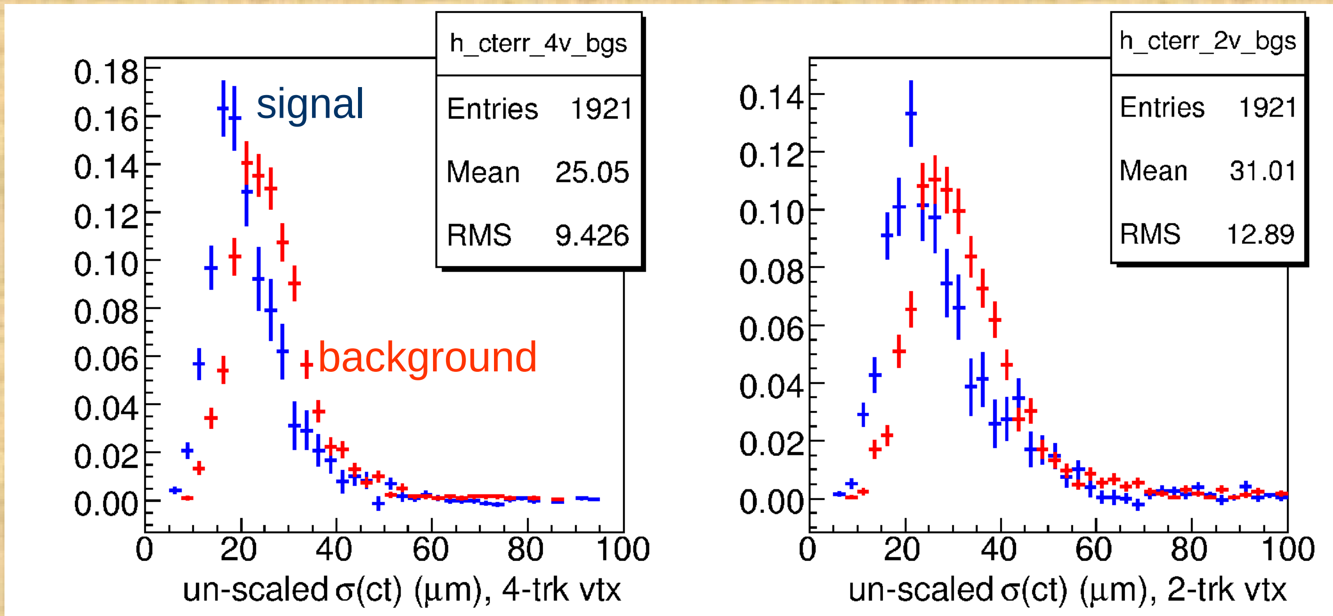
$$|A_0(0)|^2 = 0.556 \pm 0.009\ (stat) \pm 0.010\ (syst)$$
$$|A_\parallel(0)|^2 = 0.211 \pm 0.010\ (stat) \pm 0.006\ (syst)$$
$$\mathrm{d}_\parallel = -2.93 \pm 0.08\ (stat) \pm 0.04\ (syst)$$
$$\mathrm{d}_\perp = +2.96 \pm 0.05\ (stat) \pm 0.03\ (syst)$$

Proper time resolution

- The mean is of the sideband subtracted σ_{ct} resolution for a 4-track vertex is 25.05 μm (error returned by the vertex fit)

- Need to multiply by a ct resolution scale factor determined by fitting the prompt peak : s = 1.26 ± 0.02 (effect of non gaussian tails, charged particle multiplicity etc,,,)

- Estimate an average resolution on proper time of 106 fs (with a most probable value of 78 fs).



Confidence Region Construction

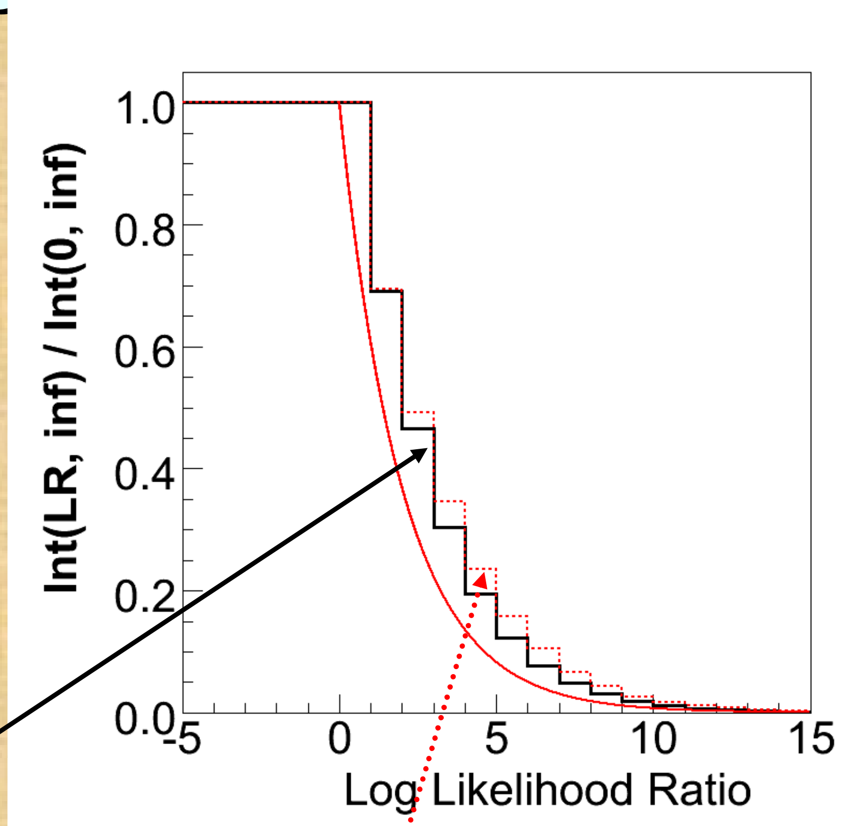
$$R(\Delta G_s, \beta_s) = \log \frac{L(\Delta\hat{G}_s, \hat{\beta}_s, \hat{\theta})}{L(\Delta G_s, \beta_s, \hat{\theta}')}$$

^ = parameters that maximize likelihood L

θ' = nuisance parameters which maximize L for a specific choice of $\Delta\Gamma_s, \beta_s$

Use pseudo–experiments to calculate:

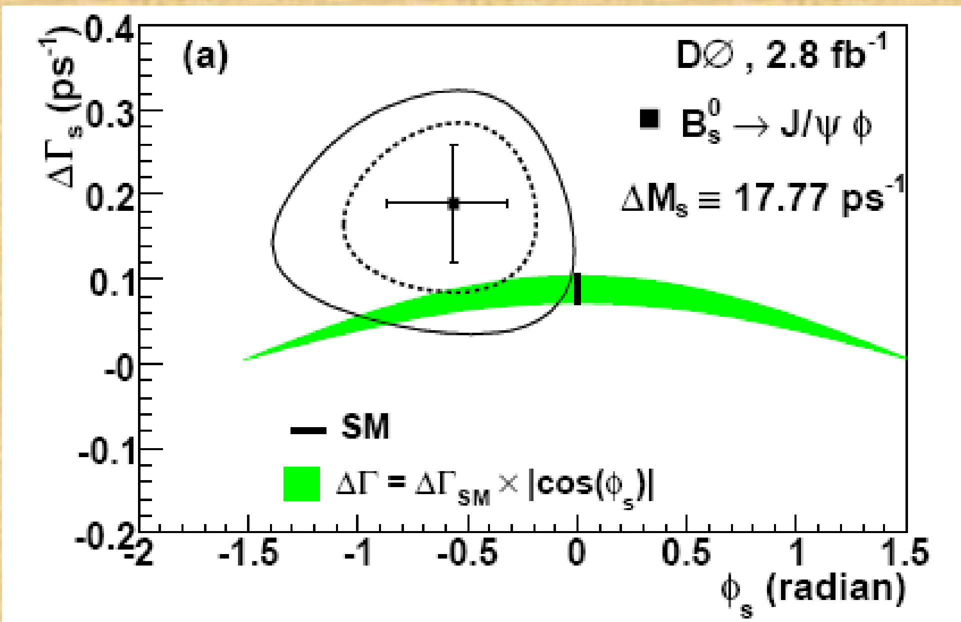
$$p_{value} = \int_{Rdata}^{\infty} f(R, \Delta G_s, \beta_s) dR$$

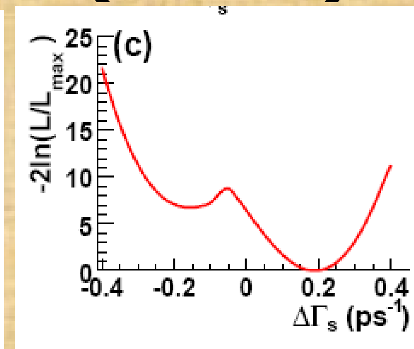


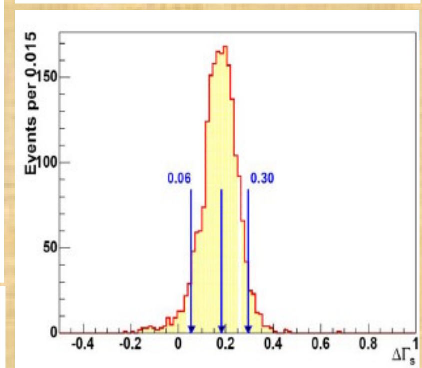
Guarantees the frequentistic coverage of the quoted C.L.
Takes into account non-asymptotic behaviour of likelihood, i.e. log(L) non-parabolic, and possibility of large fluctuation of likelihood shape from experiment-to-experiment

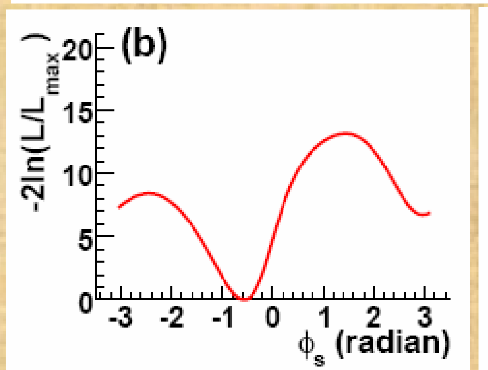
Include systematics via an additional coverage adjustment varying nuisance parameters within 5σ of their uncertainties and choosing worst case (higher P-value) to define the confidence regions

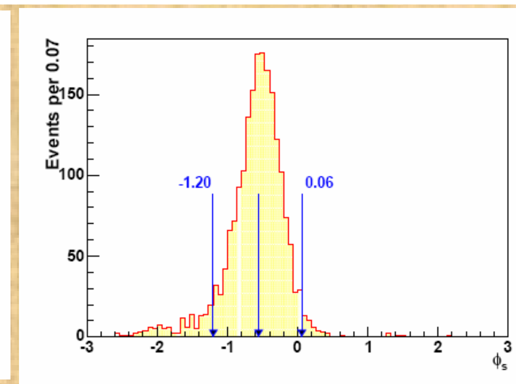
DØ Results (tails)











- 90% CL range from pseudoexperiment significantly different from what obtained from likelihood profile

$$-1.20 < \varphi_s < 0.06 \;\; rad \quad \text{vs}$$

$$-1.10 < \varphi_s < -0.10 \;\; rad$$